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MINNEAPOLIS
ST. PAUL

PHONE BROADWAY 5437

BARBEE STEEL & IRON CO.

EAST WATER & HURON STS.
MILWAUKEE, WIS.

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A View of the
LUDLUM STEEL COMPANY'S PLANT
WATERVLIET, N. Y.

LUDLUM STEEL CO.

Carbon and Alloy
Tool Steel

HIGH SPEED STEEL

CONSISTENTLY UNIFORM

General Offices and Works
WATERVLIET, N. Y.

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LUDLUM STEEL COMPANY

Carbon and Alloy Tool Steels

Established

1854

HIGH SPEED STEEL

CONSISTENTLY UNIFORM

General Offices and Works
WATERVLIET, N. Y.

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General Offices

WATERVLIET, NEW YORK

Branch Offices:

NEW YORK.....New York City
MASSACHUSETTS.....Boston
PENNSYLVANIA.....Philadelphia
" .....Pittsburgh
OHIO.....Cleveland
" .....Cincinnati
ILLINOIS.....Chicago
ITALY.....Società I. A. F. A. Genoa

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INTRODUCTION

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LUDLUM STEEL COMPANY
WATERVLIET, NEW YORK

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INTRODUCTION

The Ludlum Steel Company is one of the oldest established high grade tool steel mills in America, founded in the year 1854. Our Pompton brand tool steel is probably one of the most widely known high grade American steels. Our mill has grown from a comparatively small crucible plant to one of the largest high grade tool steel producing mills in the country. We make nothing but high grade tool steel, therefore our melters and rolling mill men are highly skilled in the expert handling of this special steel.

The crucible process is one of the oldest methods of making high grade steel. The product is governed by the raw material used, therefore even though the highest form of skilled control be applied to the melting and working of this steel, it is of no avail if the raw material contains some "unlooked for" impurities. That is one of the reasons why various melts of crucible steel, made from the same high grade raw material, differ very largely in their work and efficiency. The Ludlum Steel Company, recognizing this very serious defect in the highest grade crucible steel, started to investigate methods of melting wherein full refining could be accomplished, the crucible process being purely one of remelting.

The basic and acid open hearth process produces a steel which is partly refined, but does not go far enough. It is possible when the same high

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grade charge is used as in the crucible process, to produce high grade steel in the open hearth furnace, but this process has many variables and for that reason, instead of continuously getting a reliable high grade product, many mysterious things happen to open hearth melts, which are undoubtedly due to occluded gases.

The chemical analysis of high grade crucible steel can be duplicated in the open hearth but the quality of steel is distinctly different. Twenty years ago, electric furnaces were being substituted as a very probable means of eradicating the dangerous gases which are to be found in solution in steel. We were one of the pioneers in this investigation and we have experimented with practically every known type of electric furnace and have developed a special form of "electric crucible furnace" wherein we get all of the benefits common to the crucible and the full refining possible with the electric furnace.

Our customers have found that our steels are purer and give better results in service, than any other type of steel, whether it be crucible or electric. The usual electric furnace, of which there are perhaps a few hundred in operation in this country, has been developed for *quantity* production. As these furnaces produce a far purer grade of steel than the best open hearth, the opportunities for these furnaces are very great where automobile and structural alloy steels are concerned. These furnaces are therefore manufactured with two ideas in view, *quantity* and *quality*.

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Our electric crucible furnace, which is the outcome of our many years of experience, produces the highest grade of carbon and alloy tool steels, and has been designed for *quality*, which is the all important point where high grade tool steel is concerned. Individuality in the production of steel, was important in the days of the crucible steel, and is just as important now when superior methods of melting have been developed. It is our opinion, and has been fully substantiated in practice, that the furnaces used for melting tool steel *should be designed for that purpose, and that purpose alone.*

Pure tool steel, in the ingot form, can be ruined in the rolling mill if great care is not taken with the reheating and rolling mill temperatures, also in the quality of mechanical work. *We believe that we are the only steel mill in this country which has equipped its reheating furnaces with pyrometer control.* These pyrometers give us ready means of checking up the expert furnacemens' knowledge of temperature, and we have carefully worked out in our laboratory the correct temperatures for reheating steel, the speed at which this steel is to be heated, and the length of time it has to be soaked at various temperatures. We have also investigated the number of passes and the amount of mechanical work in each pass, also the temperature at which every grade of steel shall pass through the last roll in the rolling mill and a definite speed of cooling for the bars. The finishing temperatures and cooling

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temperatures are carefully checked and controlled by a special form of "optical pyrometer." Our hammer shop is controlled in exactly the same way, therefore we are in a position to justifiably claim, that our carbon and alloy tool steels are melted under the best conditions possible and are mechanically worked and heat treated under the finest methods of practical and scientific control.

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CUSTOMERS' INFORMATION

Terms

The terms are net cash—thirty days, unless otherwise specially agreed.

Quotations

All quotations are for immediate acceptance and prices are subject to change without notice.

Sales

Orders and contracts of sale are accepted subject to provision that strikes, fires, accidents and other causes of delay beyond our control, shall relieve us from prompt fulfillment thereof.

Shipments

All deliveries are made F. O. B. cars at our works unless otherwise specially arranged. Shipments by express will be made only at customer's request and expense, or whenever the weight is less than the railroad will accept as freight.

Extras

Extra charges will be made in accordance with the classification in this catalogue. Boxing, casing and barrelling at cost.

Payments

Checks and drafts should be drawn to the order of the Ludlum Steel Company, and forwarded to Watervliet, New York.

Warranty

We will replace any steel which, if properly selected and used, shall prove defective, but we will not allow claims for labor or damage.

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HOW TO ORDER TOOL STEEL AND ALLOY STEEL

When ordering tool steel always specify the following:

1. The grade.
2. The size and shape.
3. The carbon-temper or the purpose for which the steel is to be used.
4. Annealed or not.

It is particularly important when ordering tool steel which is to be made into costly tools and dies that the above points should be carefully observed.

In the event of your specifying the grade and purpose for which the tool steel will be used and omitting to specify the carbon-temper, we will furnish the same temper as the one last supplied you for the same purpose. In the event of no prior purchase having been made for this class of material, we will use our judgment and select the steel which we think is best suited for the purpose.

If bars are to be machined, order at least $\frac{1}{4}$" larger than the finished size.

When ordering die blocks, whether forged or cut from the bar, give the following information:

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The length, the width, and the depth or thickness, allowing at least $\frac{3}{8}''$ all over each way for machining. Tool steel bars run from 6′ to 12′ according to weight. We reserve the right to make up a full bar of two pieces unless otherwise specially ordered. Bars of unusual length supplied to order at small extra charge.

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TOOL STEEL CLASSIFICATION

Applying to all Grades of Tool-Steel Except High-Speed Steel All Dimensions Inclusive

Intermediate Sizes Take the Next Higher Extra

ROUND, SQUARE, OCTAGON AND HEXAGON

⅛ to 2 Inches.....Base

Inches	Extra per lb. Cents
2⅛ to 3	1.0
3⅛ to 4	1.5
4⅛ to 5	2.0
5⅛ to 6	2.5
6⅛ to 7	3.0
7⅛ to 8	3.5
8⅛ to 9	4.0
9⅛ to 10	5.0

Inches	Extra per lb. Cents
1/16 to ¼	0.5
7/16 to ⅜	1.0
5/16 and 11/32	2.0
¼ and 9/32	3.0
3/16	5.0
5/32	10.0
1/8	18.0

FLAT

⅛ to 2 inches thick x 3/16 to 2 inches wide.....Base

Inches	Extra per lb. Cents
⅛ x 3/16	20.0
⅛ x ¼	15.0
⅛ x 5/16	8.0
⅛ x ⅜	4.0
⅛ x 7/16 to ½	3.0
⅛ x 9/16 to 7	2.0
⅛ x 7⅛ to 8	3.0
3/16 x ¼	5.0
3/16 x 5/16	4.0
3/16 x ⅜	3.0
3/16 x 7/16 to ⅝	2.0

Inches	Extra per lb. Cents
3/16 x 11/16 to 2	1.5
3/16 x 2⅛ to 7	1.0
3/16 x 7⅛ to 8	2.0
¼ x 5/16 to ⅜	2.0
¼ x 7/16 to ⅝	1.5
¼ x 11/16 to 2	1.5
¼ x 2⅛ to 7	1.0
¼ x 7⅛ to 8	2.0
5/16 x ⅜ to ⅝	1.5
5/16 x 11/16 to 8	1.0
⅜ x 7/16 to 8	1.0

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TOOL STEEL CLASSIFICATION—*Continued*

Inches	Extra per lb. Cents
7/16 x 1/2 to 8	1.0
1/2 x 5/16 to 8	1.0
5/16 x 2 1/8 to 8	1.0
5/8 to 2 x 2 1/8 to 7	1.0
5/8 to 1 3/4 x 7 1/8 to 8	1.0
1 7/8 to 2 x 7 1/8 to 8	1.5
2 1/8 to 3 x 2 1/8 to 5	1.0
2 1/8 to 3 x 5 1/8 to 8	1.5
3 1/8 to 4 x 3 1/8 to 6	1.5
3 1/8 to 4 x 6 1/8 to 8	2.0
4 1/8 to 5 x 4 1/8 to 7	2.0
4 1/8 to 5 x 7 1/8 to 8	2.5
5 1/8 to 6 x 5 1/8 to 8	2.5
6 1/8 to 7 x 6 1/8 to 7	3.0
6 1/8 to 8 x 7 1/8 to 8	3.5

BEVEL

Single Bevel—1 cent per pound advance over the regular extra size of the corresponding flat.

Double Bevel—2 cents per pound advance over the regular extra for size of the corresponding flat.

CUTTING TO SPECIFIED SINGLE AND MULTIPLE LENGTHS

	Cents per lb.
24 inches and over	0.5
18 to 23 15/16 inches	1.0
12 to 17 15/16 inches	1.5
6 to 11 15/16 inches	2.0

Less than 6 inches, special prices.

ANNEALING

	Cents per lb.
Annealing Carbon Tool-Steels	1

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TUNGSTEN-STEEL CLASSIFICATION

Applying to all Grades of Tungsten-Steels, Including High-Speed Tool-Steel All Dimensions Inclusive

Intermediate Sizes Take the Next Higher Extra

ROUND, SQUARE AND OCTAGON

⅛ to 2 inches ..... Base

Inches	Extra per lb. Cents
2⅛ to 2½	2.0
2⅝ to 3	2.5
3⅛ to 3½	3.0
3⅝ to 4	3.5
4⅛ to 4½	4.0
4⅝ to 5	4.5
5⅛ to 5½	5.0
5⅝ to 6	5.5
6⅛ to 6½	6.0
6⅝ to 7	6.5
1/16 to ¼	2.0
1/16 to ⅜	3.5
1/16 to 11/32	6.0
¼ to 9/32	8.5

FLAT

⅛ to 2 inches thick x ⅛ to 2 inches wide ..... Base

Inches	Extra per lb. Cents
⅛ x 1/16	40.0
⅛ x ¼	30.0
⅛ x 5/16	20.0
⅛ x ⅛ to 2	14.0
1/16 x ¼ to 3	14.0
¼ x 5/16 to ½	8.0
¼ x ⅛ to 1	5.0
¼ x 1⅛ to 4	3.0
1/16 x ⅛ to ⅝	5.0
1/16 x ¼ to 1	3.5
1/16 x 1⅛ to 4½	3.0
⅜ x 7/16 to ¾	3.0
⅜ x 7/16 to 1½	3.0
⅜ x 1⅛ to 5	2.5
7/16 x ½ to 1	3.0
7/16 x 1⅛ to 5½	2.5
½ x ⅛ to 1	2.5
½ x 1⅛ to 6	2.0
9/16 x ⅛ to 1	2.5
9/16 x 1⅛ to 6	2.0
⅛ to 2 x 2⅛ to 4	2.0
⅛ to 2 x 4⅛ to 7	4.0
2⅛ to 3 x 2⅛ to 4	2.0
2⅛ to 3 x 4⅛ to 7	4.0

ANNEALING

	Cents per lb.
Annealing Tungsten-Steels	2

BEVEL

Same classification as Flat plus 10 cents per lb. extra for shape.

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TUNGSTEN-STEEL CLASSIFICATION —*Continued*

Cutting to Specified Single and Multiple Lengths

	Extra per lb. Cents
24 inches and over	1
18 to 23 15/16 inches	2
12 to 17 15/16 inches	3
6 to 11 15/16 inches	4

Less than 6 inches, special prices.

High-Speed Steel Classification of Forged Discs.

	Extra per lb. Cents
Weighing above 25 lbs	6

Weighing	Extra per lb. Cents
15 to 25 lbs	10
10 to 15 lbs	12
7½ to 10 lbs	14
5 to 7½ lbs	16
3 to 5 lbs	18
2 to 3 lbs	22
1 to 2 lbs	24

Under 1 lb., flat extra price of $1.00 each.
Annealing, 2 cents per lb. extra.

High-speed Steel Classification of Forged Die Blocks

Weighing	Extra per lb. Cents
Above 25 lbs	4
15 to 25 lbs	6
10 to 15 lbs	10
7½ to 10 lbs	14
5 to 7½ lbs	16
3 to 5 lbs	18
2 to 3 lbs	22
1 to 2 lbs	24

Under 1 lb., flat extra price of $1.00 each.
Annealing, 2 cents per lb. extra.

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LUDLUM TOOL STEEL DISCS

Furnished in any of our standard grades of carbon, alloy and high speed steels, will meet the needs of the most exacting customer, and our warehouse facilities make prompt shipment of stock sizes from the nearest point possible.

Below will be found lists showing the standard extras, that apply to carbon and high speed tool steel discs, and also a table of contents for determining weights. To obtain the pound price of any disc, add the disc extra, for the given weight, to the base price per pound of the steel desired.

In ordering discs, customers should specify overall, not finished dimensions, *as we make no allowances for finishing.*

DISC CLASSIFICATION

Weight	*Carbon and Alloy Steel*	Extra per lb. Cents
Above 25 lbs		3
15 to 25 lbs		5
10 to 15 lbs		6
7½ to 10 lbs		7
5 to 7½ lbs		8
3 to 5 lbs		9
2 to 3 lbs		11
1 to 2 lbs		12

Under 1 lb., special price. Annealing 1 cent per lb.
Above extras are for discs ½" thick and over; thinner discs at special prices.

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LUDLUM TOOL STEEL DISCS—*Continued*

Weight	HIGH-SPEED STEEL Extra per lb.	Cents
Above 25 lbs		6
15 to 25 lbs		10
10 to 15 lbs		12
7½ to 10 lbs		14
5 to 7½ lbs		16
3 to 5 lbs		18
2 to 3 lbs		22
1 to 2 lbs		24

Above extras are for discs ½" thick and over; thinner discs at special prices.

Under 1 lb., flat extra price $1.00 each. Annealing, 2 cents per lb.

DISC WEIGHTS

A convenient method of finding the approximate weight of tool steel discs is the following:

The values given in the table below are the decimal equivalents of fractional parts of a foot. Multiply the weight per foot of bar steel of the same diameter as disc (see pages, 138-139) by that value which represents the thickness of the disc desired. This gives the approximate weight of the disc in pounds and is sufficiently accurate for practical purposes.

DECIMAL EQUIVALENTS OF FRACTIONAL PARTS OF A FOOT

Inches	0	⅛	¼	⅜	½	⅝	¾	⅞
0	.00	.01	.02	.03	.04	.05	.06	.07
1	.08	.09	.10	.12	.13	.14	.15	.16
2	.17	.18	.19	.20	.21	.22	.23	.24
3	.25	.26	.27	.28	.29	.30	.31	.32
4	.33	.34	.35	.36	.38	.39	.40	.41
5	.42	.43	.44	.45	.46	.47	.48	.49
6	.50	.51	.52	.53	.54	.55	.56	.57
7	.58	.59	.60	.62	.63	.64	.65	.66
8	.67	.68	.69	.70	.71	.72	.73	.74
9	.75	.76	.77	.78	.79	.80	.81	.82
10	.83	.84	.85	.87	.88	.89	.90	.91
11	.92	.93	.94	.95	.96	.97	.98	.99

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RING EXTRAS

The following simple rule for computing the price of rings is based on the fact that a ring carries the same forging-extra as a solid disc of the same outside measurements, plus a charge for the steel represented by the hole and a charge of three cents per pound for the labor of making the hole.

RULE

Multiply weight of solid disc (page 17) by base-price of steel and divide product by weight of ring. Add disc extra as per disc classification for the solid disc and three cents per lb. for labor of making hole. The sum will be the selling-price per pound of the ring.

EXAMPLE

To find the price of a ring made of Ludlum Carbon Steel 9½ inches outside diameter, 1 inch thick, with 4¼ inch hole:

Base-price of steel assumed at 16 cents per pound:

Weight of 9 ½ x 1 inch solid disc	20 lbs.
Weight of 4 ¼ x 1 inch disc (hole)	4 lbs.
Weight of ring	16 lbs.
Applying the rule $\frac{20 \times 16}{16}$ =	20 cents per lb.
Disc extra for a 20 lb. disc. (p. 16)	5 cents per lb.
Charge for making hole	3 cents per lb.
Price without annealing	28 cents per lb.
Annealing, if specified	1 cent per lb.
Net price of annealed ring	29 cents per lb.

The difference between the base-price of the steel, 16 cents, and the net selling-price of the annealed ring, 29 cents, is the "ring extra"—in this case, 13 cents.

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FORGED LUDLUM DIE BLOCKS

Ludlum Die Blocks can be furnished in any of our straight carbon steels and in a number of alloy steels. We shall be glad to suggest the compositions which we consider best suited for the use intended; nature of work turned out, quantity of output desired, and amount of labor expended in making the die, being important factors taken into consideration.

"Ludlum Quality" guarantees the excellence of our forged die blocks and every attention is given to furnishing material that will give superior results.

Forged die blocks take the following extras over and above the regular base price of the steel from which they are made.

CARBON AND ALLOY STEEL

Weight	Extra per lb. Cents
Above 25 lbs	2
15 to 25 lbs	3
10 to 15 lbs	5
7½ to 10 lbs	7
5 to 7½ lbs	8
3 to 5 lbs	9
2 to 3 lbs	11
1 to 2 lbs	12

Under 1 lb., flat extra price 25c. each.
Annealing, 1c. per pound.

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ALLOYS AND THEIR EFFECT UPON STEEL

NICKEL

CHROMIUM

NICKEL CHROMIUM

CHROME-VANADIUM

MANGANESE

TUNGSTEN

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ALLOYS AND THEIR EFFECT UPON STEEL

In view of the fact that alloy steels are coming into a great deal of prominence, it would be well for the users of these steels to fully appreciate the effects of the alloys upon the various grades of steel. We have endeavored to summarize the effect of these alloys so that the users can appreciate their effect, without having to wade through a considerable amount of written matter and then, perhaps, not get the crux of the situation.

NICKEL

Nickel may be considered as the toughest among the non-rare alloys now used in steel manufacture. Originally nickel was added to give increased strength and toughness over that obtained with the ordinary rolled structural steel and little attempt was made to utilize its great possibilities so far as heat treatment was concerned.

The difficulties experienced have been a tendency towards laminated structure during manufacture and great liability to seam, both arising from a non-homogeneous melt. When extra care is exercised in the manufacture, particularly in the melting and rolling, many of these difficulties can be overcome.

The electric steel furnace, of modern construction, is a very important step forward in the melt-

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ing of nickel steel; neither the crucible process nor basic or acid open hearth furnaces give such good results. It is also necessary that small ingots be made so as to cut down undue piping.

In rolling, great care must be exercised in reheating the billet so that the steel is correctly soaked and the rolling must not be forced; too big reductions per pass should not be indulged in as these set up a tendency towards seams.

Nickel steel has remarkably good mechanical qualities when suitably heat-treated, and it is preeminently adapted for case hardening. It is not difficult to machine low nickel steel, therefore it is in great favor where easy machining properties are of importance.

Nickel influences the strength and ductility of steel by being dissolved directly in the iron or ferrite; in this respect differing from chromium, tungsten and vanadium. The addition of each 1% nickel up to 5% will cause an approximate increase of from 4,000 to 6,000 pounds per square inch in the tensile strength and elastic limit over the corresponding carbon steel and without any decrease in ductility. The static strength of nickel steel is affected, to some degree, by the percentage of carbon; for instance, steel with .25% carbon and 3.5% nickel has a tensile strength, in its normal state, equal to a straight carbon steel of .5% with a proportionately greater elas-

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tic limit and retaining all the advantages of the ductility of the lower carbon.

To bring out the full qualities of nickel it must be heat-treated, otherwise there is no object in using nickel as an alloy with carbon steel, the additional cost is not justified by increased strength.

Nickel has a peculiar effect upon the critical ranges of steel, the critical range being lowered by the percentage of nickel; in this respect it is similar to carbon only more marked. Generally speaking, nickel steel requires a lower heat-treating temperature than chrome steel or tungsten steel, and in this respect is very similar to manganese.

Nickel can be alloyed with steel in various percentages, each percentage having a very definite effect on the micro-structure. For instance, a steel with .2% carbon and 2% nickel has a pearlitic structure but the grain is much finer than if the straight carbon were used. With the same carbon content and say 5% nickel, the structure would still be pearlitic, but much finer and denser, therefore capable of withstanding shock, and having greater dynamic strength. With about .2% carbon and 8% nickel, the steel is nearing the stage between Pearlite and Martensite, and the structure is extremely fine, the Ferrite and Pearlite having a tendency to orientiate, as seen in a purely Martensite structure. .2% carbon with 15% nickel is entirely Martensite. Higher percentages of nickel change the Martensite structure to Austenite, the

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steel then being non-magnetic. The higher percentages, that is 30% to 35% nickel, are used for valve seats, valve heads, and valve stems, as the alloy is a poor conductor of heat and is particularly free from any tendency towards corrosion or pitting from the action of the waste gases of the internal combustion engine.

To obtain the full effect of nickel as an alloy, it is essential that the correct percentage of carbon be used. High nickel and low carbon will not be more efficient than lower nickel and higher carbon, but the cost will be much greater. Generally speaking, heat-treated nickel alloy steels are about 2 to 3 times stronger than the same steel annealed. This point is very important as many instances have arisen where nickel steel is incorrectly used, being employed when in the annealed or normal state.

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CHROMIUM

Chromium when alloyed with steel has the characteristic function of opposing the disintegration and reconstruction of Cementite. This is demonstrated by the changes in the critical ranges of this alloy steel taking place slowly; in other words, it has a tendency to raise the Ac range (decalescent points) and lower the Ar range (recalescent points). Chromium steels are therefore capable of great hardness, due to the rapid cooling being able to retard the decomposition of the Austenite.

The great hardness of chromium steels is also due to the formation of double carbides of chromium and iron. This condition is not removed when the steel is slightly tempered or drawn. This additional hardness is also obtained without causing undue brittleness such as would be obtained by any increase of carbon. The degree of hardness of the lower chrome steels is dependent upon the carbon content, as chromium alone will not harden iron.

The toughness so noticeable in this steel is the result of the fineness of structure; in this instance the action is similar to that of nickel, and the tensile strength and elastic limit is therefore increased without any loss of ductility. We then have the desirable condition of tough hardness, making chrome steels extremely valuable for all purposes requiring great resistance to wear, and in higher chrome contents resist-

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ance to corrosion. All chromium alloy steels offer great resistance to corrosion and erosion. In view of this, it is surprising that chromium steels are not more largely used for structural steel work and for all purposes where the steel has to withstand the corroding action of air and liquids. Bridges, ships, steel buildings, etc., would offer greater resistance to deterioration through rust if the chromium alloy steels were employed.

Prolonged heating and high temperatures have a very bad effect upon chromium steels and in this respect they differ from nickel steels, which are not so affected by prolonged heating, but chromium steels will stand higher temperatures than nickel steels when the period is short.

Chromium steels due to their admirable property of increased hardness without the loss of ductility, make very excellent chisels and impact tools of all types, although for die blocks they do not give such excellent results as can be obtained from other alloy combinations.

For ballbearing steels, where intense hardness with great toughness and ready recovery from temporary deflection is required, chromium as an alloy offers the best solution.

Two per cent chromium steels, due to their very hard tough surface, are largely used for armour

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piercing projectiles, cold rolls, crushers, drawing dies, etc.

The normal structure of chromium steels, with a very low carbon, is roughly pearlitic up to 7 per cent., and martensitic from 8 to 20 per cent, therefore the greatest application is in the pearlitic zone or the lower percentages.

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NICKEL CHROMIUM

A combination of the characteristics of nickel and the characteristics of chromium, as described, should obviously offer a very excellent steel as the nickel particularly affects the ferrite of the steel and the chromium the carbon. From this combination we are able to get a very strong ferrite matrix and a very hard tough Cementite. The strength of a strictly pearlitic steel over a pure iron is due to the pearlitic being a layer arrangement of Cementite running parallel to that of a pure iron layer in each individual grain. The ferrite, i.e., the iron, is increased in strength by the resistance offered by the Cementite which is of the staple iron carbon combination or carbide known as Fe_3C. The Cementite, although adding to the tensile strength, is very brittle and the strength of the pearlite is the combination of the ferrite and Cementite. In the event of the Cementite being strengthened, as in the case of strictly chromium steels, an increased tensile strength is readily obtained without loss of ductility, and if the ferrite is strengthened then the tensile strength and ductility of the metal is still further improved.

Nickel chromium alloy represents one of the best combinations available at the present time. The nickel intensifies the physical characteristics of the chromium and the chromium has a similar effect on the nickel.

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For case hardening, nickel chromium steels seem to give very excellent results. The carbon is very rapidly taken up in this combination, and for that reason is rather preferable to the straight nickel steel.

With the mutually intensifying action of chromium and nickel there is a most suitable ratio for these two alloys, and it has been found that roughly 2½ parts of nickel to about 1 part of chromium gives the best results. Therefore, we have the standard types of 3.5% nickel—1.5% chromium, 1.5% nickel—.6% chromium and the various intermediary types. This ratio, however, does not mean the whole story of nickel chromium combinations, and many surprising results have been obtained with these alloys when other percentage combinations have been employed.

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CHROME VANADIUM

Much has been stated and published concerning vanadium as an alloy with chromium and the benefits to be derived from chrome vanadium steel over and above those obtainable from chromium nickel.

Vanadium has a very marked effect upon alloy steels rich in chromium, carbon or manganese. Vanadium itself when combined with steel, very low in carbon, is not so noticeably beneficial as the same carbon steel higher in manganese, but if a small quantity of chrome is added, then the vanadium has a very marked dynamic effect. Therefore, it would seem that vanadium has the effect of intensifying the action of chromium and manganese or that vanadium is intensified by the action of chromium or manganese.

Vanadium has the peculiar property of readily combining with ferrite, also the carbon forming carbides and is to be found in solid solution in the ferrite. The ductility of carbon vanadium steels is therefore increased, likewise the ductility of chrome vanadium steels.

The full effect of vanadium is not felt unless the temperatures, to which the steel is heated for hardening, are raised considerably; therefore, it is necessary that a certain amount of soaking takes place so as to get the necessary equalization. This is true of all cementitic compounds, of which vanadium is one.

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Chrome vanadium steels also have a tendency for greater depth of hardening and anti-fatigue properties than can be obtained from straight chromium steels. It would appear that the intensification of the chrome and manganese in the alloy steel accounts for this peculiar phenomenon.

Vanadium is also a very excellent scavenger for either removing the harmful gases or causing them to enter into solution with the metal in such a way as to largely obviate their harmful effects. Chrome vanadium steels have been claimed, by many steel manufacturers, and users, to be preferable to nickel chrome steels. While not wishing to pass judgment on this, it should be borne in mind that the chrome vanadium steel, which is tested, is generally compared with a very low nickel chromium alloy steel (the price factor entering into the situation), but equally good results, can be obtained by nickel chromium steels of suitable analysis.

Where price is the leading factor, many instances are arising where a stronger steel can be obtained from the chrome and vanadium than the nickel chrome. It will be safe to say that each of these two systems of alloys have their own particular fields and chrome vanadium steel should not be regarded as the sole solution for all problems, neither should nickel chromium.

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MANGANESE

Manganese adds considerably to the tensile strength of steel but is dependent on the carbon content. High carbon materially adds to the brittleness, whereas low carbon pearlitic manganese steels are very tough and ductile and are not at all brittle, providing the heat-treating is correct.

Manganese steel is very susceptible to high temperatures and prolonged heating.

Low carbon pearlitic manganese steel is a very efficient steel but its efficiency is entirely dependent on the temperature to which it is heated for hardening or the temperature used for annealing. Low carbon pearlitic manganese steel made in the electric furnace seems to be more efficient than the same chemical analysis steel made by either the open hearth or crucible process. No reason has, as yet, been assigned for this peculiar phenomenon, but it is believed that the removal of the harmful gases, particularly oxygen and nitrogen, are responsible.

Manganese when added to steel has the effect of lowering the critical range; 1% manganese will lower the upper critical point 60 degrees F. The action of manganese is very similar to that of nickel in this respect, only twice as powerful; as an instance, 1% nickel would have the effect of lowering the upper critical range from 25 degrees to 30 degrees F.

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Low carbon pearlitic manganese steel, heat-treated, will give dynamic strength which cannot be equalled by low-priced and necessarily low content nickel steels. In many instances it is preferable to use high grade manganese steel, rather than low content nickel steel.

High manganese steels or Austenite manganese steels are used for a variety of purposes where great resistance to abrasion is required, the percentage of manganese being from 11 to 14 per cent, and carbon 1 to 1.50 per cent. This steel is practically valueless unless heat-treated; that is, heated to about yellow red and quenched in ice water. The structure is then Austenite and the air cooled structure of this steel is Martensite. Therefore, this steel has to be heated and very rapidly cooled to obtain the ductile Austenite structure.

Manganese between 2 and 7 per cent is a very brittle material when the carbon is about 1 per cent or higher, therefore quite valueless. Below 2 per cent manganese steel low in carbon is very ductile and tough steel.

The high content manganese steels are known as the "Hadfield manganese steels," having been developed by Sir Robert Hadfield. Small additions of chrome up to 1 per cent increase the elastic limit of low carbon pearlitic manganese steels without affecting the steel in its resistance to shock, but materially decrease the percentage of elongation.

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Vanadium added to low carbon pearlitic manganese steel has a very marked effect, increasing greatly the dynamic strength and changing slightly the susceptibility of this steel to heat treatments, giving a greater margin for the hardening temperature. Manganese steel with added vanadium is most efficient when heat-treated.

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TUNGSTEN

Tungsten, as an alloy in steel, has been known and used for a long time. The celebrated and ancient Damascus steel being a form of tungsten alloy steel. Tungsten and its effects, however, did not become generally realized until Robert Mushet experimented and developed his famous Mushet steel and the many improvements made since that date go to prove how little Mushet himself understood the peculiar effects of tungsten as an alloy.

Tungsten acts on steel in a similar manner to carbon, that is it increases its hardness, but is much less effective than carbon in this respect. If the percentage of tungsten and manganese is high, the steel can be hardened by cooling in the air. This effect is directly opposite to that of carbon. It was this combination that Mushet used in his well known steel.

The principal use of tungsten is in high speed tool steel but here a high percentage of manganese is distinctly detrimental, making the steel liable to fire crack, very brittle and weak in the body, less easily forged and annealed. Manganese should be kept low and a high percentage of chromium used instead.

The tungsten-chromium steels, when hardened, retain their hardness even when heated to a dark cherry red by the friction of the cutting or the heat arising from the chips. This characteristic led to the

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term "red hardness" being applied to this class of steel, and it is this property that is responsible for the increase of cutting speeds in the tungsten chrome alloy, that is high speed steel.

Tungsten when added to steel up to 6% does not have the property of red hardness any more than carbon tool steel, providing the manganese or chromium is low. Tungsten has a rapidly increasing cutting efficiency up to 13%, thereafter falling until 14%, then increasingly efficient until 18% or more is used.

If chromium is alloyed with tungsten, then a very definite red hard effect is noticed with a great increase of cutting efficiency. The maximum red hard cutting efficiency of the tungsten chrome steel seems to be a definite chemical analysis, ratio, but there are various mechanical and other reasons why this ratio is not used for high speed steel, as high chromium content steel is very easily spoiled by the high heats necessary in its heat-treatment.

Very little is known of the actual function of tungsten, although a vast amount of experimental work has been done. It is possible that when the effect of tungsten with iron carbon alloys is better known, a greater improvement can be expected from these steels. Tungsten has been tried and is still used by some steel manufacturers for making punches, chisels, and other impact tools. It has also been used for springs and has given very good results although

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other less expensive alloys give equally good results, and in some instances, better.

Tungsten is largely used for permanent magnets. In this its action is not well understood. In fact, the reason why steel becomes a permanent magnet is not at all understood. Theories have been evolved but all are open to serious questioning. The principal effect of tungsten, as conceded by leading authorities, is that it distinctly retards separation of the iron carbon solution, removing down to atmospheric temperature the lowest recalescent point.

A peculiar property of tungsten when used in the iron carbon alloys is that when a temperature of 1750°F is not exceeded, it does not interfere with the carbide change, thereby affecting the temperatures of the recalescent points, whereas when the hardening temperature is raised above 1850°F., a most remarkable effect is conveyed upon the falling transformation points, preventing their formation entirely, down to about the atmospheric temperature.

The lowering of the carbide change, which is produced by heating tungsten steels to over 1850°F., and is the real cause of the red hard properties of these alloys, is not understood and there is no direct evidence to show what actually happens at these high temperatures.

There is every reason to believe that when the tungstide Fe_3W is present, it gradually goes into

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solution as the temperature is raised above 1550°F., the amount of compound present being higher as the tungsten is increased: When completely in solution, the temperature of the carbide change (recalescent point) is lowered on cooling. It is quite an open question, however, whether this lowering is entirely due to the Fe_2W in solution or whether some other chemical change also occurs.

At a temperature above 1850°F., there may be chemical reactions between the iron and tungsten carbide, which give a new compound resulting in the disappearance of the critical point at the falling temperature 1300°F. and the appearance of another point at a lower temperature.

Other combinations, in which there should be no free tungstide of iron, give the same lowering of the carbide change after heating to high temperatures; therefore the subject is still surrounded with a fair amount of uncertainty.

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CARBON AND ALLOY TOOL STEEL

ITS COMPOSITION AND HEAT TREATMENT

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CARBON AND ALLOY TOOL STEEL

Its Composition and Heat Treatment

Much mystery has been created by those partially initiated in the art of tool steel hardening and heat treatment. As a matter of fact, there are no mysteries as far as the well known phenomenon of hardening and tempering is concerned. This change in steel follows certain predetermined courses, and providing the fundamental laws governing this process are observed, no difficulties will be experienced, and the entire operation is one of great simplicity although calling for a considerable amount of care and observation.

The natural state of iron with carbon as an alloy, known as carbon steel, is the normal state, that is the annealed state. The two factors, heat and time, play very important parts with the result that steel can be found in many different stages from the hardened state to the fully annealed state.

Carbon steel, when heated to a temperture above its critical range, takes on a certain crystal formation and endeavors to assume another definite crystal formation on cooling. This ultimate or final crystal formation is known as the soft stage, and providing sufficient time be given for the crystals to arrange themselves, the steel is known as annealed. In the event of this natural arrangement of the crystals

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being prevented by any cause, we have the various intermediary stages, such as unannealed steel, hardened steel and tempered steel.

From the above it is obvious that it is essential first to put the steel in its natural or normal state. This is done by heating the steel slowly and uniformly to a temperature just above its critical point, called the decalescent point, and allowing the steel to cool very slowly from this temperature. The decalescent point (decalescent or Ac on the rising temperature and recalescent or Ar on the falling temperature) is caused by the rearrangement of the crystal formation of the steel. The uniform heating, which has taken place up to this point, is suddenly halted, the steel being entirely unaffected by external temperatures. When the crystals have taken on their new formation, the temperature continues to rise. This phenomenon, of which there are several scientific theories, is present in all steels, very marked in high carbon steel and less perceptible in low carbon steel, occurring at a temperature variable with the chemical content of the steel. To harden the steel, so that it is in its hardest and toughest state, the crystal formation of the steel should be fixed as soon as this rearrangement of crystals has taken place. This is best done by immediately quenching the steel at this temperature.

In the event of the temperature of the steel being raised above the decalescent point, the crystals in their new formation start to enlarge, and

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if the tool is chilled or fixed at the higher temperature, then the steel will have a larger grain and be correspondingly weak; this is known among steel men as being "overheated;" if the temperature is still higher, then "burnt."

The "overheated" steel can be reclaimed by being heated again to the correct temperature and allowed to cool slowly from this critical point; then reheated to just above the decalescent point and quenched in the usual way. The steel is now refined and almost as good as before. In the event of the steel being "burnt," then it is impossible for any subsequent heat treatment to redeem this steel, and it should be immediately scrapped. The critical temperature or decalescent point (Ac 2.3) has certain magnetic characteristics. That is, when raised to this temperature through the process of the rearrangement of the crystals, the steel is not affected by magnetism and is known as non-magnetic. This point, although a parallel with the hardening temperature has nothing to do with it, but serves a very useful purpose in enabling the tool steel hardener to determine the correct hardening temperature for any given carbon tool steel (not alloy tool steel), when lacking the necessary equipment for easily locating the decalescent point.

All tool steels should be tested so as to determine the correct hardening temperature. This can be very easily accomplished, either by taking

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note of the lowest temperature at which the steel is non-magnetic, or by taking a piece of the tool steel and nicking the bar in a number of places, say 7 nicks about 1" apart, and raising the temperature at one end of the bar until the steel is a light yellow heat, the other end being a black heat, noting the temperature of the 7 sections between the nicks. Then chill the whole in water, preferably at 65°F.

The bar should be carefully dried and each of the sections broken off at the nicks by a sharp blow of the hammer. Each section at the nick has a different grain. The end of the bar which had been overheated will have a very coarse bright open grain. This grain will gradually get finer and less fiery until the grain appears to be very fine and of a velvety nature. The next immediate section beyond this will have the same fine velvety nature on the outside but the center will appear coarse. The temperature at this point is too low and the one section higher where the grain is fine and velvety throughout is the correct hardening temperature.

Many tool hardeners are under the impression that to make steel very hard it is necessary to harden at an increasingly high temperature. This is incorrect, as the increased hardness conveyed to the steel by quenching at excessive temperatures is very small (in some cases the steel is actually softer) and the strength of the steel which is necessary to

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maintain the cutting edge or strength resistance to compression, etc., diminishes at a very quick rate.

The correct hardening temperature for carbon tool steels is the lowest temperature at which the steel will harden.

All tool steels should be tempered slightly to remove the strains, and to impart to the steel great toughness.

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HIGH SPEED STEEL

MOHAWK EXTRA

MOHAWK

MOHAWK EXTRA

Tool-Holder Bits

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MOHAWK EXTRA

High Speed Steel

" Mohawk Extra " represents the latest developments in electro-metallurgy; consistently uniform and is designed to withstand the most exacting demands of high duty machine tools and will stand very high speeds and heavy cuts and low speeds and heavy cuts. It is quite unexcelled for turning toughened alloyed steels, and will work at a red heat for a long period without the edge failing. It is particularly adapted for taps and dies, twist drills, milling cutters, and reamers; can be readily forged and is particularly free from a tendency to check and crack when being hardened. It will carry a very keen edge, and is an excellent " finishing steel."

" Mohawk Extra " can be readily annealed, therefore it is very economical when being machined to shapes. This steel is remarkable for its density and homogeneity. Where the equipment of the machine shop is not sufficiently powerful to use the full cutting capacity of " Mohawk Extra," it is still pre-eminently economical on account of the very long periods this steel can be run without having to be resharpened.

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MOHAWK EXTRA

High Speed Steel

Brand No. 820

Price per pound.....

Base sizes:

Extra for sizes, annealing, etc., see pages 14-15.

Our "Mohawk Extra" represents the highest development in high speed steel and is used in very large quantities. It is capable of withstanding the highest cutting load that can be developed on the modern high-duty machine tool. It will stand deeper cuts, greater feeds and higher speed than any other high speed steel made.

We recommend it for lathe, shapers, planers, boring mill tools, milling cutters, form cutters, finishing tools, dies, reamers, and for all purposes where heavy duty cutting or finishing is required. It can be furnished in annealed and unannealed bars, blocks, and dies.

HEAT TREATMENT: See pages 119-122.

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MOHAWK

High Speed Steel
Brand No. 800

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 14-15.

" Mohawk " of high speed steel has been developed for use in extremely heavy cutting and is particularly useful where machine tools are not of the most modern design. Our "Mohawk" steel is renowned for its high degree of excellency, purity, and uniformity. We strongly recommend this steel for all high speed cutting tools, insert saw teeth, wood working tools, special dies, hot work, and all steel and cast iron turning and machining generally.

HEAT TREATMENT: See pages 119-122.

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MOHAWK EXTRA

HIGH SPEED STEEL
Tool-Holder Bit
Brand No. 830

These tools are made out of our well-known "Mohawk Extra" High Speed Steel, cut to standard tool-holder lengths with 30-degree angle ends. Each piece is hardened, ready to be ground and put to work. This steel will give the same excellent satisfaction and will perform the same heavy duty work as our "Mohawk Extra."

Furnished from stock in 5-pound, 10-pound, and larger boxes; one size or assorted sizes in a box.

Prices on application.

STANDARD LENGTHS, READY TO SHIP

$\frac{1}{4}$	inch	square,	$2\frac{1}{2}$	inches	long
$\frac{5}{16}$	"	"	$2\frac{1}{2}$	"	"
$\frac{3}{8}$	"	"	3	"	"
$\frac{7}{16}$	"	"	$3\frac{1}{2}$	"	"
$\frac{1}{2}$	"	"	4	"	"
$\frac{5}{8}$	"	"	$4\frac{1}{2}$	"	"
$\frac{3}{4}$	"	"	5	"	"

We also carry in 12-inch lengths, for tool-holders, a large assortment of treated squares and flats up to 1 square inch in section.

Price per pound:.....

DIRECTIONS FOR TREATED BARS

Do not heat to cut, but nick the bar on all four sides upon an emery-wheel; then break cold to desired length and grind to shape on a dry wheel.

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LUDLUM CARBON TOOL STEELS

POMPTON SPECIAL

POMPTON EXTRA

POMPTON

ELBA

F. SPECIAL

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LUDLUM CARBON TOOL STEELS

High Grade straight carbon tool steels are manufactured by us in the following brands: Pompton Special, Pompton Extra, Pompton, Elba, and F. Special. Each of these grades is supplied in the usual tempers as per pages 59-60-61. All our steels are manufactured in our own specially designed electric crucible furnace, which is a proved superior method of manufacturing steel to the old crucible process.

All molten steel, when cooling, is subjected to local segregation and the occluded gases are liberated into microscopic bubbles. To reduce these occluded gases to a minimum is a very expensive process and calls for high refinements. It is further necessary that this, the highest grade steel, should be very low in metalloid impurities. It is difficult to trace the differences by chemical analysis between our various grades of straight carbon steels. The chemical laboratory although capable of laying bare the various metalloid impurities finds it very difficult to trace gases which are to be found in solution in the steel.

After very careful investigation, we have found that by submitting our highest grade straight carbon steel to additional refining in the furnace, we have been able to reduce the occluded gases to the lowest point. This is very expensive and calls for a considerable amount of care on the part of the

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melter and, as high grade steel produced in the melting shop can have its value reduced in the rolling mill, very special attention has to be paid to the heating and rolling temperatures.

All our furnaces are equipped with pyrometer control, enabling us to regulate our rolling mill temperatures within a few degrees; great attention being paid to the finishing temperature at the last pass in the rolling mill. The same applies when the steel is hammered. Our high grade carbon steels are carefully watched and worked during the process of their manufacture and represent the very finest straight carbon steels that have yet been produced.

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CARBON AND ALLOY TOOL STEEL, TEMPER NUMBERS, CORRESPONDING USES AND HARDENING HEATS

TEMPERS

EXTRA HARD 3X

For roll corrugating and chill roll turning tools; for graver tools and all purposes where extreme hardness and fine cutting edge is required.

To Forge—*Heat to bright cherry red* 1425°-1475°*F.*

To Harden—*Heat slowly and uniformly to a cherry red, approximately* 1375°-1425°*F., quench in oil or water at* 65°*F.; draw to requirements.*

HARD 3

For lathe, planer and slotter tools generally, brass working tools, drawing dies, razors and tools requiring great hardness and fine edge.

To Forge—*Heat to bright cherry red,* 1450°-1500°*F.*

To Harden—*Heat slowly and uniformly to full cherry red, approximately* 1385°-1435°*F.; quench in oil or water at* 65°*F.; draw to requirements.*

EXTRA TOUGH AND HARD 33

For small taps, trimming and cutting dies, threading dies, circular cutters, forming and boring tools;

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also for twist drills, screw dies, ball races, peen hammers, granite points, plugs, drawing dies, mandrels, and edge tools generally, razors, and all purposes where a keen tough edge is required.

To Forge—*Heat to bright red,* 1500°-1550°*F.*

To Harden—*Heat slowly and uniformly to a bright cherry red, approximately* 1400°-1450°*F.; quench in oil or water at* 65°*F.; draw to requirements.*

STAR—EXTRA TOUGH

For milling cutters, taps, trimming dies, saw, swages, circular cutters, reamers, mill tools, wood-working tools, form and thread tools, and for all purposes where a very tough and hard edge is required. Welds with care.

To Forge—*Heat to bright red,* 1500°-1550°*F.*

To Harden—*Heat to bright cherry red, approximately* 1420°-1470°*F; quench in either oil or water at* 65°*F.; draw to requirements.*

TOUGH 4

For punches, large cutting and trimming dies, drop dies; for cold work, mining drills, small shear knives, hand chisels, and all purposes where great toughness with hardness is required. Welds with care.

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To Forge—*Heat to bright red,* 1500°-1550°*F.*

To Harden—*Heat slowly and uniformly to a bright cherry red, approximately* 1450°-1500°*F.; quench in oil or water at* 65°*F.; draw to requirements.*

CHISEL STEEL 44

For large shear knives, punches, chisels, hammers, sledges, cold sets, track chisels, drop forging dies, hammer dies, boiler makers' tools, and all purposes where impact tools are required. Welds with care.

To Forge—*Heat to salmon red,* 1600°-1650°*F.*

To Harden—*Heat to a full bright cherry red, approximately* 1450°-1525°*F.; quench in oil or water at* 65°*F.; draw to requirements.*

WELDING DIE STEEL 5

For drop forging, bolt and rivet headers, hot drop forging dies, ring dies, steel-faced dies, and for all purposes where an extremely tough and hard steel is required. Welds easily.

To Forge—*Heat to salmon red about* 1600°-1700°*F.*

To Harden—*Heat to very bright cherry red, approximately* 1475°-1550°*F.; quench in water or oil; draw to requirements.*

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POMPTON SPECIAL

Carbon Tool Steel
Brand No. 250

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.
Supplied in all tempers, see pages 59-61.

"Pompton Special" is the finest quality straight carbon tool steel that can be made and will give great satisfaction, meeting the most severe requirements for cutting and impact tools such as dies, punches, taps, screw dies, chisels, etc. It is particularly free from any tendency to warp or twist on hardening. We strongly recommend this steel where quality is of prime importance.

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POMPTON EXTRA

Carbon Tool Steel

Brand No. 240

Price per pound .....

Base sizes:

Extra for sizes, annealing, etc., see pages 12-13.

Supplied in all tempers, see pages 59-61.

"Pompton Extra" is of similar analysis to our finest grade, Pompton Special, but a little less high in refinements. We recommend this steel for lathe and planer tool dies, finishing tools, shear blades, and all purposes where quality is of first importance. This steel will harden to a good depth and is particularly free from any tendency to warp or twist.

POMPTON

Carbon Tool Steel

Brand No. 230

Price per pound .....

Base sizes:

Extra for sizes, annealing, etc., see pages 12-13.

Supplied in all tempers, see pages 59-61.

"Pompton" tool steel is excellent for all purposes where straight carbon steels are used. For the price, this steel can not be equalled and although a little less pure than our better grades, will give excellent results for all purposes where cutting tools or impact tools are used. It will be found to be very reliable and a safe steel to handle.

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ELBA

Carbon Tool Steel
Brand No. 220

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.
Supplied in all tempers, see pages 59-61.

"Elba" tool steel, although a comparatively low priced steel, will give excellent satisfaction and in some instances is as economical as a higher grade of steel, the chemical analysis being very similar to our high grades but not so super-refined.

F. SPECIAL

Carbon Tool Steel
Brand No. 210

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.
Supplied in all tempers, see pages 59-61.

"F Special" tool steel is our lowest priced straight carbon tool steel and of remarkable purity. We recommend this steel for all purposes where our highest grade steel is used, but where such high refinements are not so necessary.

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LUDLUM ALLOY TOOL STEELS

PEQUOT
ALBANY
ONEIDA
MOHICAN
IROQUOIS
IROQUOIS SPECIAL
OSWEGO
OTSEGO
OTSEGO SPECIAL
SENECA
HURON
POMPTON DRAWING DIE
HUDSON
MOHAWK EXTRUSION
APACHE
SIOUX
SIWASH
SALISH
ARAPAHO
CHEYENNE

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LUDLUM ALLOY TOOL STEELS

The modern day requirement for tool steels has necessitated the addition of various alloys to increase the life and effectiveness of tool steel. We have found that with the electric crucible furnace it is possible to get greater efficiency with alloys of chrome, vanadium, tungsten, molybdenum, cobalt, nickel, etc., than can be obtained from the crucible process. The result of our numerous experiments has shown that alloyed tool steels for some classes of work will give much better results than straight carbon tool steel. These steels generally require special heat treatment and should be very carefully handled. Advice should be given to the hardeners to carefully follow the heat treating instructions supplied with each bar of alloyed tool steel.

In the manufacture of alloyed steels, practice has shown that these steels are prone to many faults but we have, after much research, been able to reduce these to a minimum and we have no hesitation in saying that the alloyed tool steels manufactured by us are purer and are higher in refinements than any other alloy steel of similar analysis.

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PEQUOT

Alloy Tool Steel

Brand No. 300

Price per pound.....

Base sizes:

Extra for sizes, annealing, etc., see pages 12-13.

Supplied in all tempers, see pages 59-61.

"Pequot" brand has greater depth of hardness than straight carbon steel and will last longer in service than our high grade straight carbon tool steel. For impact work, where excessive jar is felt on the cutting edge of the tool, Pequot brand is pre-eminently suitable.

To Harden—*Heat extremely slow to about* 50°*F. higher than temperature given for carbon steel similar temper number.*

Note: The full effect of this alloy tool steel is not brought out unless the steel is very slowly heated and held at the quenching temperature at least 10 to 30 min.

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ALBANY

Alloy Tool Steel

Brand No. 400

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.
Supplied in all tempers, see pages 59-61.

Chrome and vanadium when used as an alloy in tool steel, imparts a greater life to cutting edges and the tools will stand up longer under vibratory stress. "Albany" is the result of very careful investigation in the art of alloying these elements and we believe that here we have produced an alloyed tool steel that is superior to any other similar type steel.

This steel is made under the same high refinement as our Pompton Special and represents an extremely pure steel. We strongly recommend it for expensive taps and screw dies, punches, cutters, and all purposes where a lasting and very hard cutting edge is desired.

To Harden—*Heat very slowly about 50°F. higher than temperature given for carbon steel similar temper number.*

Note: The full effect of this alloy tool steel is not brought out unless the steel is very slowly heated.

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ONEIDA

Alloy Tool Steel
Brand No. 710
Non-Shrinking Steel

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.

"Oneida" is the result of our extensive experience in the production of a reliable non-shrinking, oil hardening steel that is free from a tendency to check on hardening, and yet will not move. Our "Oneida" brand, even with the most delicate shapes will, when hardened, be entirely free from any tendency to warp, crack, or move in any way. We strongly recommend this steel for taps, dies, plug and ring gauges, press tools, hobs, and all purposes where a keen edge is required.

HEAT TREATMENT

To Forge—*Heat slowly and uniformly to* 1450°*F. and forge carefully. Do not harden at forging heat.*

To Harden—*Heat very slowly and uniformly to* 1400°-1450°*F. Quench in oil only and draw to a very light straw if necessary.*

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MOHICAN

Alloy Tool Steel
Brand No. 330
Special Tough and Hard

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.

"Mohican" has been manufactured to meet the demand for a very high grade, pure, hardened steel for taps and dies. This steel is a very tough and hard steel and will carry an extremely keen edge, hardening with a minimum amount of movement. Although not quite so non-shrinking as our Oneida brand, the steel will be found to give wonderful satisfaction. As a steel for taps and dies, chasers, milling cutters, press tools, master taps, it is quite unexcelled.

HEAT TREATMENT

To Forge—*Heat slowly and uniformly to* 1600°*F. Do not harden at forging heat.*

To Harden—*Heat slowly and uniformly at* 1450°-1475°*F. Quench in oil or water at* 65°*F.; draw to requirements.*

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IROQUOIS

Gold Label Finishing Steel
Brand No. 540

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 14-15.

"Iroquois" is a special alloy steel designed for all purposes where a very hard, keen edge is required. For use as a finishing tool this steel gives remarkable results. We recommend it for turning chilled rolls, corrugating chilled rolls, special circular forming tools, also very excellent for gun barrel drills and reamers, engraving tools, and highly recommended for automatic machine forming tools.

HEAT TREATMENT

To Forge—*Heat slowly and uniformly to* 1450°*F. Allow to cool slowly after forging.*

To Harden—*Heat slowly and uniformly to* 1375°–1500°*F.; do not soak, quench in oil or water at* 65°*F. Draw to dark straw or requirements.*

Note: We recommend pack or lead pot hardening.

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IROQUOIS SPECIAL

Gold Label Finishing Steel
Brand No. 550

Price per pound.....

Base sizes:

Extra for sizes, annealing, etc., see pages 14-15.

" Iroquois Special " is similar to our Iroquois brand but higher in refinements, harder, and will carry a keen edge longer. We strongly recommend it for turning chilled rolls, corrugating chilled rolls, special circular forming tools, excellent for gun barrel drills and reamers, engraving tools and all purposes where a very hard, keen, smooth edge is required; and is quite unexcelled for circular forming tools for automatic machines.

HEAT TREATMENT

To Forge—*Heat slowly and thoroughly to* 1450°*F.; forge slowly, allow to slowly cool after forging.*

To Harden—*Heat slowly and uniformly to* 1375°–1500°*F.; do not soak; quench in oil or water at* 65°*F.; draw to a straw color, or requirements.*

Note: We recommend pack or lead pot hardening.

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OSWEGO

Special Alloy Pneumatic Chisel Steel
Brand No. 420

Price per pound:.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.

Special vanadium alloy tool steel designed for pneumatic chisels, rivet sets, hand chisels, and for all purposes where the tool has to stand a great rapidity of blows. This steel has a very hard and durable cutting edge, specially adapted for chiseling hard and tough materials. It is particularly free from any tendency to crack in the shank.

HEAT TREATMENT

To Forge—*Heat slowly and uniformly to* 1600°*F. Do not harden at forging heat.*

To Harden—*Heat slowly and uniformly to* 1450°-1500°*F. and quench in oil or water at* 65°*F. Draw to requirements. For pneumatic chisels or rivet sets, heat the shank slowly and uniformly to* 1450°-1500°*F. and quench in oil. Draw the temper to* 1000°*F. or until it just shows red in the dark, quench in oil or allow to cool in the air.*

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OTSEGO

Special Pneumatic Rivet Set Steel
Brand No. 430

Price per pound.....

Base sizes:

Extra for sizes, annealing, etc., see pages 12-13.

This special vanadium alloy steel is the result of many tests and investigations and is one of the finest steels that have yet been developed for this exacting purpose. When properly heat treated, it has no tendency to crack under the head, which is one of the principal faults of rivet set steel.

Our "Otsego" brand will stand up remarkably well in the cup, resisting the tendency to soften due to the hot rivet. It is very simple to heat treat and will be found to be a very reliable steel in every way. We recommend it for all vibratory work but not for pneumatic chisels or slow compression bull dies.

HEAT TREATMENT

To Forge—*Heat slowly and uniformly to* 1600°-1650°*F.*; *allow to slowly cool after forging.*

To Harden—*Heat the rivet set slowly and uniformly all over to* 1525°-1575°*F. and hold at this temperature for about ten minutes. Chill the cup or working face of the rivet set by holding it under a cold water faucet until the working face is cold. This should be done speedily so that the temperature in the body of the tool does not materially fall. The steel should then be chilled out in oil. The body of the tool should then be heated up to about* 700°*F., keeping the working face of the tool not hotter than purple, according to the purpose for which the tool is to be used, then cool in oil.*

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OTSEGO SPECIAL

Bull Die Steel for Hot Rivet Work

Brand No. 910

Price per pound.....

Base sizes:

Extra for sizes, annealing, etc., see pages 12-13.

Our "Otsego Special" brand for slow compression riveting and hot die work is the result of an unusual combination of alloys and has phenomenal qualities. For bull dies, where a slow compression is used on hot rivets, this steel gives remarkable satisfaction. *We supply this steel in heat treated lengths and it should not be subjected to any further heat treatment whatsoever.* The steel will be found soft enough to machine with care. It is so extraordinarily tough and unaffected by the influence of heat from hot rivets that the dies when once made are extremely durable and will last many times longer than those made from other brands of steel manufactured for bull dies.

In the event of the bull die wearing after a long period, the cup can be redressed by being turned; the tool should not under any circumstances be annealed or heat treated when being redressed.

Our "Otsego Special" steel represents the same remarkable development over ordinary bull die steel as high speed steel does, over carbon steel. This special heat treated alloy steel is sold in all round sizes from 1½" to 5" in diameter

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SENECA

Alloy Punch and Die Steel
Brand No. 500

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 14-15.

" Seneca " is a tungsten alloy steel and gives very good results for punches, dies and all purposes where a very tough, durable edge is required. This steel has a very close dense structure and will outlast similar steels for this class of work. It hardens to a great depth, carries a very hard, keen, cutting edge and has great anti-fatigue properties.

HEAT TREATMENT

To Forge—*Heat slowly and uniformly to* 1600°-1700°*F; allow to very slowly cool off.*

To Harden—*Heat slowly and uniformly to* 1500°-1600°*F. Hold at this temperature sufficiently long enough to soak the heat right through the tool. Quench in oil or water at* 65°*F. Draw to requirements.*

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HURON

Special Alloy Punch and Die Steel
Brand No. 650

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 14-15.

Our "Huron" brand is the result of our extensive experiments in the development of an alloy steel which will give superior results for blanking silicon transformer sheets and armature discs. This brand of steel in practice has lasted two or three times longer than any other steel developed for this purpose and we recommend our "Huron" brand for punches, and dies, for thin sheets and heavy material also for extrusion, drawing, threading, forming, thread rolling and mint dies, taps, reamers, plug and ring gauges.

"Huron" is an oil hardening steel and is particularly free from any tendency to warp or twist in hardening. This steel will harden to a great depth and the life of the die after each grinding is consistently uniform.

HEAT TREATMENT

To Forge—*Heat slowly and uniformly to* 1750°-1800°*F. Allow to slowly cool after forging.*

To Anneal—*Heat slowly and uniformly to* 1650°*F., hold at this temperature according to the size of the tool and then cool extremely slowly.*

To Harden—*Heat slowly and uniformly to* 1650°*F., hold at this temperature for ten minutes or longer according to the size of the tool. Quench in oil, draw to requirements.*

Note: We recommend pack or lead pot hardening.

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POMPTON

Drawing Die Steel

Brand No. 260

Price per pound.....

Base sizes:

Extra for sizes, annealing, etc., see pages 12-13.

We have developed a special steel for use in drawing dies and plugs, where many unusual properties are required. "Pompton" will shrink after each rehardening so that the worn hole will close sufficiently to allow the same to be reground and yet retain the original size.

This special steel is free from any tendency to crack or check, and will carry a very hard surface which penetrates to a good depth.

For drawing die steel, which is required to shrink, this steel is quite without an equal. It is very simple to heat treat, no special instructions having to be observed.

HEAT TREATMENT

To Forge—*Heat slowly and uniformly to* 1500°-1550°*F. Allow to slowly cool after forging.*

To Harden—*Heat slowly and uniformly to* 1450°-1500°*F. Quench in water at* 65°*F. Draw slightly to relieve strain if necessary.*

Note: For drawing dies, only the hole should be quenched, this is done best over a stream of water under pressure.

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HUDSON

Alloy Drawing Die Steel
Brand No. 520

Price per pound.....

Base sizes:

Extra for sizes, annealing, etc., see pages 14-15.

"Hudson" a special alloy steel developed for drawing dies. This steel will keep its shape on hardening and will outlast other similar steels. Our "Hudson" brand is not difficult to machine and is simple to heat treat. An intensely hard surface can be obtained coupled with great toughness. We strongly recommend this brand where long lengths of wire have to be drawn with minimum variation. Excellent plugs, gauges, mint dies, etc.

HEAT TREATMENT

To Harden—*Heat slowly and uniformly to* 1400°-1500°*F. Hold at this temperature to insure complete saturation in the steel and quench in oil or water at* 65°*F. Draw very slightly to relieve strains.*

Note: For drawing dies, only the hole should be quenched, this is done best over a stream of water under pressure.

Note: We recommend pack or lead pot hardening.

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MOHAWK EXTRUSION

Extrusion Die Steel

Brand No. 870

Price per pound.....
Base sizes:
Extra for size: annealing, etc., see pages 14-15.

This brand has been developed especially for extrusion dies and gives excellent results. "Mohawk Extrusion" is a tungsten alloy steel combining the qualities of hardness and toughness.

It is remarkably free from any tendency to soften in use, crack or surface check, and will hold up to size for extremely long runs.

HEAT TREATMENT: *Supplied on request.*

APACHE

Special Tong Bit Steel

Brand No. 850

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 14-15.

We have developed this special alloy steel to be used for tong bits and all purposes where use with hot metal is desired. Tong bits, when made of "Apache," will last in service for long periods, there being no tendency for this steel to soften under the heat. This steel will remain hard even when at a red heat.

HEAT TREATMENT: *Supplied on request.*

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SIOUX

Special Razor Steel
Brand No. 270

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.

"Sioux" brand is a very high grade steel of great purity and homogeneity, being free from any hard spots or changes in structure. This steel will forge very readily and when hardened is intensely hard, very tough, and carries an extremely fine, smooth, sharp edge of great durability.

HEAT TREATMENT

To Forge—*Heat slowly and uniformly to* 1450°-1500°*F. Allow to cool slowly after forging.*

To Harden—*Heat slowly and uniformly to* 1375°-1450°*F. and quench in oil or water at* 65°*F. Draw to requirements.*

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SIWASH

Special Roll Steel
Brand No. 920

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.

" Siwash " a very homogeneous close grained alloy steel, designed to be free from microscopic pin holes, very hard and tough yet easily machined and capable of taking a very high finish, recommended for highly polished jewelers' rolls and cold metal rolls for all purposes.

HEAT TREATMENT: *Supplied on request.*

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SALISH

Carbon Twist Drill Steel

Brand No. 280

Price Per Pound.....

Base sizes:

Extra for sizes, annealing, etc., see pages 12-13.

"Salish" has been developed specially for twist drills. It is a very tough and hard steel of the highest grade and extremely homogeneous, free from any tendency to crack in hardening, carries a keen edge, and the corners of the drill will not readily deteriorate in use.

Supplied in cold drawn bars or coils.

HEAT TREATMENT

To Harden—*Heat slowly and uniformly to* 1400°-1450°*F. Hold at this temperature according to the size, quench in oil or water at* 65°*F. Draw to requirements.*

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ARAPAHO

Special Alloy Twist Drill Steel
Brand No. 470

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.

We have developed a very high grade of alloy steel for twist drills and recommend "Arapaho" for all purposes where a tough, durable, twist drill is required. This steel will carry a very hard, keen edge and is free from any tendency to split. It is safe in hardening, no special instructions being necessary.

HEAT TREATMENT

To Harden—*Heat slowly and uniformly to* 1450°-1500°*F. Maintain at this temperature sufficiently long to allow the steel to become thoroughly saturated. Quench in oil or water at* 65°*F. Draw to requirements.*

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CHEYENNE

Special Non-Corrosive Steel
Brand No. 630

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 14-15.

In conducting a series of experiments to develop a steel which would be suitable for hot die work, we found that by the inclusion of certain alloys, we were able to produce a steel which would not corrode under acid or atmospheric conditions. This steel is remarkably tough and holds a very good cutting edge. It is hard enough to machine chilled rolls, although for this purpose it is not recommended.

We have developed this steel for use in cutlery, solving the trouble of keeping steel knives clean. A knife blade made of our special non-corrosive steel will not stain or tarnish when used for fruit or vinegar, etc. A non-rusting knife, which carries a sharp edge, will certainly recommend itself. This new non-corrosive steel should be used for all knife blades, scissors, forks, skate blades, steel rules, golf clubs, dental tools, surgical instruments, saddlery, and for all purposes where the steel is not subjected to intense heat but is required to be continuously bright.

To keep the steel in a high state of polish, it is only necessary to wash it with soap and water.

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BALL BEARING STEEL IN USE

SPECIAL BALL BEARING STEELS

PIEGAN

TETON

SPECIAL BALL BEARING STEEL EXTRA

NAVAHO

KUTANI

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BALL BEARING STEEL IN USE

Ballbearing steels can be placed in two classes: Case or carbonizing steels and straight hardening steels.

The manufacture of ball and roller bearings calls for high duty material. The balls must be made of a steel which is entirely homogeneous throughout its mass, and capable of withstanding enormous pressures for very short periods, without any tendency towards disintegration at the point of contact. It is also of prime importance that the steel shall quickly recover from temporary fatigue. The ball under load has a constant tendency to deflect at the ever advancing point of contact and this highly stressed surface must be able to recover in the time allowed between the arrival of the stressed particle from its contact with the inner race to the outer race, therefore having a period equal to half its diameter for this recovery, and when the ballbearing is subjected to very high speeds and heavy loads, the time allowed for recovery is obviously of very short duration. These conditions have resulted in the almost universal use of straight hardening steel for balls.

Ball races are subjected to even more high duty than the balls as their stressed area is virtually a line contact around the periphery of the race, and the time allowed for this highly stressed line to recover is even shorter than that of the ball. Furthermore, the

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excessive loads to which the ball is subjected are spread evenly over the surface of the ball, due to slight axial misalignment, whereas the race has but one line of highly stressed contact.

The stressed surface of a roller bearing is practically the same as that in a ballbearing but the bearing pressure per unit of surface is not quite so high, nevertheless the same high duty material is essential. We have developed a special analysis of chrome and chrome vanadium steels to take care of these enormous stresses.

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PIEGAN

Special Ball Bearing Steel
Brand No. 600

Price per pound.....

Base sizes:

Extra for sizes, annealing, etc., see pages 12-13.

This high grade ball bearing steel is very low in impurities and capable of being hardened right through; the micro-structure throughout the mass being extremely consistent. "Piegan" is quite free from any of the objectionable hard microscopic points which are so present in chrome steels due to local segregation of chrome-carbide; therefore, this steel has no tendency to spall (shell off). We recommend this brand for ball and rollers. We can supply this steel in cold drawn bars and coils. Specially heat treated—annealed.

HEAT TREATMENT

To Harden—*Heat slowly and uniformly to* 1450°-1500°*F., holding at this temperature sufficiently long to allow the steel to thoroughly saturate. Quench in oil or water at* 65°*F. Draw to requirements.*

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TETON

Special Ball Bearing Steel
Brand No. 610

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.

" Teton " has been designed especially for races and has a higher percentage of chrome than our regular ball steel, it will harden right through and has a very hard surface free from microscopic defects and will not spall in use. We supply this steel in heat-treated-annealed bars, insuring uniformity of product.

HEAT TREATMENT

To Harden—*Heat slowly and uniformly to* 1450°-1500°*F., holding at this temperature sufficiently long to insure the complete saturation of the steel. Quench in oil or water at* 65°*F. Draw to requirements.*

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SPECIAL BALL BEARING STEEL, EXTRA

Our chrome vanadium ball bearing steels are of extraordinary purity and represent the best ball bearing steel of the straight hardening type that it is possible to produce.

These steels will last longer in service than our special quality brand, and the price is but slightly higher, due to the added cost of vanadium. We strongly advocate the manufacture of high duty ball and roller bearings out of this very excellent material.

Large quantities of this analysis have been used in the best ball bearings, and have been found under tests, both in government plants and in the plants of very high class automobile manufacturers, to far excel any type of ball bearing steel. It is possible even with large balls, to harden them right through, and the same consistent micro-structure is present at the center of the ball as at the outside. The microscopical hard places, resulting in spalling, which are so common in all chrome steels, are entirely removed. This is accomplished by our special process for completely mixing the alloys in the molten steel and the full saturation of the chrome and vanadium carbides during heat treatment.

We subject this steel to a very special form of heat-treatment-annealing, similar to our special quality but with higher refinements. The steel when annealed is readily machinable and does not have any tendency to warp, twist or crack in hardening.

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NAVAHO

Ball Bearing Steel Extra
Brand No. 450

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.

"Navaho" is a very pure, high grade, vanadium chrome alloy steel and gives greater service than any other form of ball bearing steel. This steel is extremely homogeneous, the structure being very small and dense, with a complete absence of segregation or hard spots. It has high anti-fatigue properties and for ball and roller bearings is quite unequaled. We strongly recommend this brand for balls and rollers. Can be supplied in cold drawn bars and coils, heat-treated-annealed.

HEAT TREATMENT

To Harden—*Heat slowly and uniformly to* 1450°-1500°*F.; allow the steel to remain at this temperature sufficiently long to insure complete saturation in the steel. Quench in oil or water at* 65°*F. Draw to requirements.*

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KUTANI

Ball Bearing Steel Extra
Brand No. 460

Price per pound.....

Base sizes:

Extra for sizes, annealing, etc., see pages 12-13.

"Kutani" is of the highest grade, free from occluded gases and impurities. The structure is very uniform and extremely small, and of great homogeneity. This steel will harden to a great depth and has a very hard tough surface. It has high anti-fatigue properties and will give longer service than any other class of steel for this purpose. "Kutani" is designed especially for ball races and is supplied in heat-treated-annealed bars.

HEAT TREATMENT

To Harden—*Heat slowly and uniformly to* 1450°-1500°*F. and hold at this temperature sufficiently long to insure complete saturation in the steel. Quench in oil or water at* 65°*F. Draw to requirements.*

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PERMANENT MAGNET STEEL

WHY STEEL IS MAGNETIC

TUNGSTEN MAGNET STEEL

ATSINA

CHROME MAGNET STEEL

YUMA

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PERMANENT MAGNET STEEL

Many experiments have been conducted for the purpose of ascertaining the best chemical composition steel for permanent magnets and which of the many alloys, will give the best result as a permanent magnet.

The essential characteristics demanded of a permanent magnet are magnetic strength and permanency, and that the steel should also be free from any tendency to warp or check in hardening. It would appear that these apparently simple requirements could be easily obtained, but this is not so, and much groping in the dark has taken place, as the reason is not definitely known why some types of steel more than others, have the property of becoming permanent magnets. Many theories have been evolved to answer the question.

Tungsten, as an alloy in steel for permanent magnets, was pre-eminent for a long time. The most tangible theory advanced as to why tungsten has this very valuable property is very complex.

The chief desirable points and essential parts of the theory are.

1. It must have a large hysteresis coefficient to give the necessary retentivity.

2. It must be glass hard.

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3. It must have a very small micro-structure.
4. The micro-structure of the steel must consist of two salient points: the grain of the steel must be very hard and each grain surrounded with a very thin envelope of ferrite.
5. The micro-structure must be very staple and not affected by slight temperature changes.
6. When hardened, and if the steel is under great internal strains, the strains must remain in the mass for all time.
7. The steel should be capable of being readily machined.
8. The steel must be absolutely homogeneous.

The steel which gives the strongest magnetic strength and the greatest permanency is tungsten steel. This steel when hardened has a very fine grain, is glass hard, and surrounding each grain is a ferrite envelope. Each of these envelopes has the characteristics of a closed electric circuit. It is further found that the strength and permanency of a magnet varies with the size of the grain, the amount of the ferrite envelope and the hardness of the steel. Generally speaking, the strongest and most permanent magnet is the one where the grain structure is the smallest, the steel the hardest, and which has the greatest quantity of uninterrupted free ferrite envelopes.

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The tungsten in the steel readily combines with the carbon and forms double carbides, but does not, in the hardened state, prevent the formation of the ferrite envelopes or envelopes of Iron Tungstide. Chromium also has similar characteristics, and when the price of metallic tungsten was so greatly increased, the very old idea of using chromium was resorted to as a substitute for tungsten. Permanent magnets made with chromium as an alloy are very efficient and can be made as strong magnetically but not so permanent as the tungsten alloy steels. Hence the reason for their earlier abandonment.

The most peculiar part about this interesting situation is that the hitherto generally accepted theory no longer holds true, and the free ferrite hitherto considered absolutely essential is not apparently present in the chrome alloy steel. It is necessary to say here that the micro-structure of chromium steel is so extremely small that the microscopical equipment, at the present time available for metallographists, does not enable the micro-structure of hardened chromium alloy steels to be fully resolved. Under these circumstances it is still possible that the theory held for tungsten alloy and apparently not applicable to chromium alloy, would still be correct if the microscopical equipment and the etching mediums were in a state of greater development.

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ATSINA

Tungsten Magnet Steel
Brand No. 560

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 14-15.

We have, after many experiments, evolved a brand of "Tungsten Magnet Steel" which has higher coercive values and greater permanency than any other type of permanent magnet steel. "Atsina" carries a correct percentage of alloys, is of great purity and extremely homogeneous. Great care has been exercised in its manufacture so as to completely insure the desired micro-structure. This steel will harden without any tendency to check, crack or warp.

HEAT TREATMENT: *Supplied on request.*

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YUMA

Chrome Magnet Steel
Brand No. 620

Price per pound.....
Base sizes:
Extra for sizes, annealing, etc., see pages 12-13.

Our "Chrome Magnet Steel" which has been developed for use as a permanent magnet will show practically no loss in permanency after the first ageing period. "Yuma" has greater coercive force and permanence than any other type of chrome magnet steel. It will harden very readily and is free from any tendency to crack, check, or warp.

HEAT TREATMENT: *Supplied on request.*

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CARBON AND ALLOY TOOL STEEL

INSTRUCTIONS FOR

FORGING

ANNEALING

HARDENING

TEMPERING

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FORGING, ANNEALING, HARDENING AND TEMPERING

Carbon and Alloy Tool Steels

There are three important points to observe in making a successful tool:

1. The correct selection of the grade and carbon of the tool steel.
2. Careful and correct forging.
3. Correct hardening and tempering.

FORGING

Forging should be conducted with the greatest care. The blacksmith should, if his equipment will allow, choose an oil or gas fired muffle furnace as the heating agent in preference to a forge fire because of the ease of the temperature control. However, the forge fire will give very excellent results when proper care is taken. It is essential that a clean fire be used with plenty of fuel between the steel to be heated and the blast nozzle, to protect the corners of the piece from the injurious effects of the air blast on the heated metal. Slow heating is very important and the heating should never be faster than can be uniformly driven through the piece, otherwise the edges and surface of the steel will be overheated. The higher the carbon of the steel, the greater the care to be exercised so as to avoid overheating, burning, or decarbonization.

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The blacksmith must never heat the tool back on the shank any further than is absolutely necessary to take care of the forging. This is particularly important when air hardening or alloyed steels are used.

As soon as the piece has reached a uniform forging heat, it should be immediately withdrawn from the fire. Soaking, or allowing the steel to remain in the fire after it has been uniformly heated through is extremely injurious. In fact, no practice will more quickly make the steel "dry" and brittle. Vigorously hammer the steel at the high heat and with constant but more gentle strokes as the heat falls.

The steel should be hammered until the tool is black red, that is just shows red in the dark. The steel will then have the finest grain possible. Care should be taken not to hammer the steel below this temperature. After forging, the tool should be allowed to cool to black heat and then be reheated to about 1350° to 1400°F., that is a cherry red heat, and be allowed to cool in a warm place. This will remove all forging strains and refine the grain.

ANNEALING

Carbon tool steel that has been well worked under the hammer or in the rolls is generally too hard to be readily machined without first being normalized, that is annealed or softened. When machining the steel into intricate shapes for tools or dies, the steel must

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first be annealed and this is easily accomplished by the comparatively simple operation of slowly and uniformly heating the steel to about 1360° to 1400°F. The tool must, under no circumstances, be allowed to soak at this maximum temperature, but remain at this temperature just as long as is necessary for the steel to be uniformly heated through. The tool should be allowed to cool very slowly. This can be done by leaving the tool in the furnace while same is cooling or else the tool can be removed from the fire and buried in lime, powdered mica, dry ashes, etc. The tool when cold will be quite soft and readily machinable.

In heating the tool, great care should be taken that it does not come in contact with the air blast and is not subjected to draughts or to unduly oxidizing or carbonizing flames. If the tool to be annealed has been heated in an open fire or muffle furnace without being packed, the tool on cooling should show the black scale which was on the tool previous to being reheated for annealing. If this surface is disturbed at all it is due to the fire being dirty or the result of too high a temperature.

It is always advisable in annealing steel to make use of a closed box, a pipe or a muffle, and to surround the steel with powdered mica, ashes, lime, etc., so as to prevent direct contact with the flame or access of the air. When this preferable method of annealing is adopted and the tool allowed to remain in

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the packed muffle until cold, the steel on being removed is comparatively free from scale.

In annealing steel it is generally quite impossible to prevent slight surface decarbonization, and this may amount to as much as $\frac{1}{16}$" to $\frac{1}{8}$". This partial surface decarbonization is often difficult to trace by rough and ready methods, the tool will harden satisfactorily as far as a test by file is concerned, yet the surface of the steel has decarbonized to the extent of .10 to .20 carbon which will result in the failure of the tool.

Provision should always be made to allow for at least $\frac{1}{8}$" reduction on the working surface of the steel after annealing. This is to insure the full temper of the steel being present at the cutting edge of the tool. Failure to observe this simple precaution of the removal of the skin, will often result in loss not only due to a slight decarbonization but from an excessive decarbonization causing soft spots on hardening.

HARDENING

It is only possible to give general instructions for hardening, as every temper of carbon steel will require slightly different hardening temperatures and different treatments will be required according to the results desired. The advice herein given for hardening covers the general points in hardening of tempers of carbon tool steel and they only need be varied to suit the individual case. The operation is extremely

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simple but requires a great deal of care and close attention. Every detail must be carefully watched and noted, otherwise the entire cost of a very valuable die can be irretrievably lost, due to some faulty operation in either the heating or quenching. The details when carefully noted and observed render the operation of hardening comparatively simple.

The tool to be hardened should first be normalized to remove any working strains due to machining operations, etc., and to release any strains that may perhaps be left in the steel from forging or faulty annealing. The tool should be slowly warmed through, then slowly heated to a dull red 1375°-1500°F., and allowed to cool in dry lime. The tool when cold, or slightly warm, should be slowly reheated, care having been taken to see that the tool is turned a number of times to insure a uniform heat effect. This can be done best in a lead pot, salt bath, or in an oil or gas fired muffle. If a forge fire is used, care must be taken that there is plenty of fuel between the tool to be heated and the blast nozzle. It is also essential that the blast should be very gentle and the tool be turned over and over so that the heat will be conveyed across the steel in a uniform manner. Immediately the tool has been uniformly heated through, from a dull to a full cherry red, varying with the temper, that is from 1375° to 1500°F., it should be quickly withdrawn from the fire and chilled in the cooling medium. The tool should be agitated, as this will

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prevent any hardening line occurring and will cool the steel more uniformly.

The quenching medium is preferably good clean water at about 65°F. If a tough center tool is required, water 80°F. will be found most satisfactory. A brine or acid solution can be used if extreme hardness is required. It is generally better to use a higher temper and quench in cold water rather than endeavor to get extreme hardness with a lower temper steel. For slender and irregular shapes it is preferable to quench in oil at about 70° to 85°F. The oils most suitable for this purpose are as in the order named:

New fish oil.
Lard oil, 75% plus 25% paraffin.
Boiled linseed oil,
Raw linseed oil,
Extra bleached fish oil,
Cotton seed oil.
Tempering oil—60% cotton-seed,
40% mineral,
Mineral oil.

Either of the first three are excellent oils for all purposes of quenching.

Under no circumstances may the steel be quenched from a falling temperature. The temperature must always be rising or stationary. The reason for this is that the grain of the steel on quenching is always the grain of its highest temperature, therefore if the

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carbon tool steel is heated say to 1600°F. and allowed to fall until it is 1400°F., and then quenched, the steel will be found to have all the characteristics of a steel quenched at 1600°F. The steel will be overheated and comparatively useless.

In the event of the hardener overheating the steel in this manner, the tool should be allowed to cool until warm and then reheated to the lowest hardening temperature and quenched.

It will be found that the lowest hardening temperature will vary in any one given temper with the size of the piece to be hardened. It might be well to explain the reason for this, as lack of knowledge of this important point has resulted in many misunderstandings and much spoiled steel.

As previously pointed out, (see pages 43 to 47) hardening is the result of fixing the crystal formation at a given temperature. If the piece is small, the fixing of the crystal formation is quite a simple matter and takes place almost instantaneously. With a large piece, however, the heat is not radiated away from the steel as quickly; therefore the crystals attempt to take on a normal formation, and the fixing operation, that is quenching, is spread over a period which may be a matter of seconds, resulting in an exterior hardness and soft core. The steel should therefore be heated say 50° higher, and on quenching the core of the steel will be chilled, that is fixed, before it has had time to change from the hardening state

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to the soft state. The exterior of the steel will be of slightly coarser grain, but not sufficient to overheat the steel. This important detail is a simple operation to the experienced hardener and knowledge of it represents the difference between an inexperienced and experienced hardener.

TEMPERING

All tools to be used for cutting, punching or having to withstand heavy stresses should be tempered either slightly or almost to the annealed stage. If the tool is slightly tempered very little difference will be observed in the hardness, as far as cutting is concerned, but a very great difference will be noticed in the strength of the steel.

Many tools which are quite free from warpage or shrinking after being hardened, will move after tempering. The reason for this is the faulty methods of tempering and great care should be observed during this simple operation. Tempering should be done slowly and the surface of the steel should not be quickly heated, which so often happens.

In tempering the hardener generally raises the temperature of the tool until the surface of same assumes a predetermined color, such as very light straw to blue. This tint or tarnish, which is really oxide of iron, is formed on the surface of the steel by the heat of the surface and there is a distinct lag be-

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tween the surface color and the actual temperature of the surface of the tool. In fact, a piece of steel can be heated until the surface of the tool will appear a dark yellow. The tool can be kept at the same temperature for 15 minutes and the steel will then have a surface tint of dark blue, although the temperature has not changed at all.

Noting the temperature of the steel by tints is a rough and ready method and often quite suitable, but where costly tools and intricate shapes are concerned, this rough and ready method is not satisfactory and should not be employed.

It is obvious that if a hot plate or flame be applied to the surface of the tool, the exterior of the tool will quickly take on the temperature of the flame or hot plate, yet the center of the tool will be quite cool. This causes severe surface expansion, which must necessarily add to the internal strains of the steel and often cause the steel to crack.

The best method known is to immerse the tools to be tempered in a cold oil bath and slowly raise the temperature of the oil to a certain definite degree, allowing the tools to remain in the oil for 10 to 60 minutes according to the number of articles being tempered and their sizes. Then let the tools cool down with the oil. This tempering operation is very simple and is extremely inexpensive and should be adopted for all high grade tools.

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HIGH SPEED TOOL STEEL

INSTRUCTIONS FOR

FORGING

ANNEALING

HARDENING

TEMPERING

MILLING CUTTERS AND SHAPE TOOLS

LATHE AND PLANER TOOLS

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INSTRUCTIONS FOR WORKING HIGH SPEED STEEL

Cutting-Off.—To cut a piece from an annealed bar, cut off with a hack saw, milling cutter or circular saw. Cut clear through the bar; do not nick or break. To cut a piece from an unannealed bar, cut right off with an abrasive saw; do not nick or break. If of large cross-section, cut off hot with a chisel by first slowly and uniformly heating the bar, at the point to be cut, to a good lemon heat, 1800°-1850°F. and cut right off while hot; do not nick or break. Allow the tool length and bar to cool before reheating for forging.

LATHE AND PLANER TOOLS

To Forge—Gently warm the steel to remove any chill, is particularly desirable in the winter, then heat slowly and carefully to a scaling heat, that is a lemon heat (1800°-2000°F.), and forge uniformly. Reheat the tool for further forging directly the steel begins to stiffen under the hammer. Under no circumstances forge the steel when the temperature falls below a dark lemon to an orange color about 1700°F. Reheat as often as is necessary to finish forging the tool to shape. Allow the tool to cool after forging by burying the tool in dry ashes or lime. Do not place on the damp ground or in a draught of air.

The heating for forging should be done preferably in a pipe or muffle furnace but if this is

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not convenient use a good clean fire with plenty of fuel between the blast pipe and the tool. Never allow the tool to soak after the desired forging heat has been reached. Do not heat the tool further back than is necessary to shape the tool, but give the tool sufficient heat. See that the back of the tool is flatly dressed to provide proper support under the nose of the tool.

Hardening.—Slowly reheat the cutting edge of the tool to a cherry red, 1400°F., then force the blast so as to raise the temperature quickly to a full white heat, 2200°-2250°F., that is, until the tool starts to sweat at the cutting face. Cool the point of the tool in a dry air blast or preferably in oil, further cool in oil keeping the tool moving until the tool has become black hot.

To remove hardening strains reheat the tool to from 500° to 1100°F Cool in oil or atmosphere. This second heat treatment adds to the toughness of the tool and therefore to its life.

Grinding.—Grind tools to remove all scale. Use a quick cutting, dry, abrasive wheel. If using a wet wheel, be sure to use plenty of water. Do not under any circumstances force the tool against the wheel so as to draw the color, as this is likely to set up checks on the surface of the tool to its detriment

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FOR MILLING CUTTERS AND SHAPE TOOLS

Forging—*Forge as before.*

Annealing.—Place the steel in a pipe, box or muffle. Arrange the steel so as to allow at least 1" of packing, consisting of dry powder ashes, powdered charcoal, mica, etc., between the pieces and the walls of the box or pipe. If using a pipe close the ends. Heat slowly and uniformly to a cherry red, 1375°–1450°F. according to size. Hold the steel at this temperature until the heat has thoroughly saturated through the metal, then allow the muffle box and tools to cool very slowly in a dying furnace or remove the muffle with its charge and bury in hot ashes or lime. The slower the cooling the softer the steel.

The heating requires from 2 to 10 hours, depending upon the size of the piece.

Hardening and Tempering.—It is preferable to use two furnaces when hardening milling cutters and special shape tools. One furnace should be maintained at a uniform temperature from 1375° to 1450°F. while the other should be maintained at about 2250°F. Keep the tool to be hardened in the low temperature furnace until the tool has attained the full heat of this furnace. A short time should be allowed so as to be assured that the center of the tool is as hot as the outside. Then quickly remove the tool from this preheating furnace to the full heat furnace.

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Keep the tool in this furnace only as long as is necessary for the tool to attain the full temperature of this furnace. Then quickly remove and quench in oil or in a dry air blast. Remove before the tool is entirely cold and draw the temper in an oil bath by raising the temperature of the oil to from 500° to 750°F. and allow this tool to remain, at this temperature, in the bath for at least 30 minutes, insuring uniformity of temper; then cool in the bath, atmosphere or oil.

If higher drawing temperatures are desired than those possible with oil, a salt bath can be used. A very excellent bath is made by mixing two parts by weight of crude potassium nitrate and three parts crude sodium nitrate. These will melt at about 450°F. and can be used up to 1000°F. Before heating the steel in the salt bath, slowly preheat, preferably in oil. Reheating the hardened high speed steel to 1000°F. will materially increase the life of lathe tools, but milling and form cutters, taps, dies, etc., should not be reheated higher than 500° to 650°F., unless extreme hardness is required, when 1000°-1100°F., will give the hardest edge.

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NAMES	COLOR SCALE	CENT.	FAHR.
12 White		1204°	2200°
11 Light Yellow		1079°	1975°
10 Lemon		996°	1825°
9 Orange		941°	1725°
8 Salmon		899°	1650°
7 Bright Red		843°	1550°
6 Bright Cherry Red		774°	1425°
5 Cherry or Full Red		746°	1375°
4 Medium Cherry		677°	1250°
3 Dark Cherry		635°	1175°
2 Blood Red		566°	1050°
1 Faint Red		482°	900°

Note: The above is a graphic suggestion of the relation between heat colors and temperatures. Such a scheme can be **only approximately** correct.

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HEAT COLORS

In Moderate Diffused Daylight, with Approximate Temperatures

COLOR SCALE

Names.	Fahr. degrees	Cen. degrees
White	2200	1204
Light Yellow	1975	1079
Lemon	1825	996
Orange	1725	941
Salmon	1650	899
Bright Red	1550	843
Bright Cherry Red	1425	774
Cherry or Full Red	1375	746
Medium Cherry	1250	677
Dark Cherry	1175	635
Blood Red	1050	566
Faint Red	900	482

The above is a graphic suggestion of the relation between heat colors and temperatures. Such an illustration can only be *approximately correct.*

For comparison of Fahrenheit and Centigrade Scales, see pages 130 and 131.

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TEMPERING TABLE

Temperature for 1 hour		Color	Temperature for 8 min.		Suggested Uses
F	C		F	C	
370	188	Faint Yellow	460	238	Scrapers, Brass Turning Tools, Reamers, Taps, Milling Cutters, Saw Teeth.
390	199	Light Straw	510	265	Twist Drills, Lathe Tools, Planer Tools, Finishing Tools.
410	210	Dark Straw	560	293	Stone Tools, Hammer Faces, Chisels for hard work, boring cutters.
430	221	Brown	610	321	Trepanning Tools, Stamps.
450	232	Purple	640	337	Cold Chisels for ordinary work, Carpenters' Tools, Picks, Cold Punches, Shear Blades, Slicing Tools, Slotter Tools.
490	254	Dark Blue	660	349	Hot Chisels, Tools for hot work, Springs.
510	265	Light Blue	710	376	Springs, Screw Drivers.

Note—It will be noted that two sets of temperatures in Fahrenheit and Centigrade degrees are shown, one being specified for a time interval of eight minutes, and the other one hour. Articles to be tempered should be placed in the bath, the temperature then being brought up to that shown in the table and held for the time indicated. This method gives results far superior to the old and the long draw at the lower temperature will put the steel in the best condition of all.

Oil baths of fresh cotton seed or cylinder oil can be safely used up to a temperature of 500 degrees Fahr. Above this use a fused salt bath of some kind.

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USEFUL INFORMATION

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THERMOMETER SCALE

Freezing point = 32° Fahr. = 0° Cent.

Boiling point = 212° Fahr. = 100° Cent.

The Fahrenheit thermometer is generally used in the United States, and the Centigrade thermometer in countries using the metric system. In many metallurgical treatises in English, however, Centigrade temperatures are also used.

To convert degrees Centigrade into degrees Fahrenheit, multiply by nine, divide the product by 5, and add 32.

To convert degrees Fahrenheit into degrees Centigrade first subtract 32, multiply the remainder by 5 and divide the product by 9.

EXAMPLES

To find the equivalent in Fahrenheit degrees of 600 degrees Centigrade:

$$\text{Deg. Fahr.} = \frac{9 \times 600}{5} \text{ plus } 32 = 1112°$$

To find the equivalent in Centigrade degrees of 1112 degrees Fahrenheit:

$$\text{Deg. Cent.} = \frac{(1112 - 32)\,5}{9} = \frac{1080 \times 5}{9} = 600°$$

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TEMPERATURES

Degrees Fahrenheit and Corresponding Centigrade						Degrees Centigrade and Corresponding Fahrenheit					
F.	C.	F.	C.	F.	C.	C.	F.	C.	F.	C.	F.
32....	0	700....	371	1040....	560	0....	32	350....	662	520....	968
212....	100	720....	382	1060....	571	100....	212	360....	680	530....	986
400....	204	740....	393	1080....	582	200....	392	370....	698	540....	1004
420....	216	760....	405	1100....	593	210....	410	380....	716	550....	1022
440....	227	780....	416	1120....	604	220....	428	390....	734	560....	1040
460....	238	800....	427	1140....	615	230....	446	400....	752	570....	1058
480....	249	820....	438	1160....	626	240....	464	410....	770	580....	1076
500....	260	840....	449	1180....	637	250....	482	420....	788	590....	1094
520....	271	860....	460	1200....	648	260....	500	430....	806	600....	1112
540....	282	880....	471	1220....	659	270....	518	440....	824	610....	1130
560....	293	900....	482	1240....	670	280....	536	450....	842	620....	1148
580....	305	920....	493	1260....	681	290....	554	460....	860	630....	1166
600....	316	940....	504	1280....	693	300....	572	470....	878	640....	1184
620....	327	960....	516	1300....	705	310....	590	480....	896	650....	1202
640....	338	980....	527	1320....	716	320....	608	490....	914	660....	1220
660....	349	1000....	538	1340....	727	330....	626	500....	932	670....	1238
680....	360	1020....	549	1360....	738	340....	644	510....	950	680....	1256

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TEMPERATURES—*Continued*

Degrees Fahrenheit and Corresponding Centigrade						Degrees Centigrade and Corresponding Fahrenheit					
F.	C.	F.	C.	F.	C.	C.	F.	C.	F.	C.	F.
1380....	749	1740....	949	2080....	1138	690....	1274	860....	1580	1030....	1886
1400....	760	1760....	960	2100....	1149	700....	1292	870....	1598	1040....	1904
1420....	771	1780....	971	2120....	1160	710....	1310	880....	1616	1050....	1922
1440....	782	1800....	982	2140....	1171	720....	1328	890....	1634	1060....	1940
1460....	793	1820....	993	2160....	1182	730....	1346	900....	1652	1070....	1958
1480....	804	1840....	1004	2180....	1193	740....	1364	910....	1670	1080....	1976
1500....	816	1860....	1015	2200....	1204	750....	1382	920....	1688	1090....	1994
1520....	827	1880....	1026	2220....	1216	760....	1400	930....	1706	1100....	2012
1540....	838	1900....	1038	2240....	1227	770....	1418	940....	1724	1110....	2030
1560....	849	1920....	1049	2260....	1238	780....	1436	950....	1742	1120....	2048
1580....	860	1940....	1060	2280....	1249	790....	1454	960....	1760	1130....	2066
1600....	871	1960....	1071	2300....	1260	800....	1472	970....	1778	1140....	2084
1620....	882	1980....	1082	2320....	1271	810....	1490	980....	1796	1150....	2102
1640....	893	2000....	1093	2340....	1283	820....	1508	990....	1814	1160....	2120
1660....	904	2020....	1105	2360....	1294	830....	1526	1000....	1832	1170....	2138
1680....	915	2040....	1116	2380....	1305	840....	1544	1010....	1850	1180....	2156
1700....	927	2060....	1127	2400....	1316	850....	1562	1020....	1868	1190....	2174

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HIGH SPEED STEEL, WEIGHTS OF FLATS

POUNDS PER INCH

Size ins.	½″	⅝″	¾″	⅞″	1″	1¼″	1½″	1⅝″	1¾″	1⅞″	2″	2¼″	2½″	2¾″	3″	3½″	4″	5″	6″	7″
¼	.020	.024	.030	.035	.040	.045	.050	.055	.060	.070	.080	.090	.100	.110	.120	.140	.160	.200	.240	.280
⅜	.030	.037	.045	.052	.060	.067	.074	.082	.090	.105	.120	.134	.150	.165	.180	.210	.240	.300	.360	.420
½	.040	.050	.060	.070	.080	.090	.100	.110	.120	.146	.160	.180	.200	.220	.240	.280	.320	.400	.480	.560
⅝	.050	.062	.075	.087	.099	.113	.123	.137	.150	.174	.200	.224	.250	.273	.300	.350	.400	.500	.600	.700
¾	.060	.075	.090	.105	.120	.134	.150	.164	.180	.209	.240	.270	.300	.330	.360	.420	.495	.600	.718	.836
⅞	.070	.088	.105	.122	.140	.157	.174	.193	.207	.243	.280	.320	.350	.383	.420	.490	.558	.700	.836	.975
1	.....	.100	.120	.140	.160	.180	.200	.220	.240	.280	.320	.360	.400	.440	.480	.558	.638	.800	.957	1.12
1⅛	.....	.113	.135	.157	.180	.202	.224	.247	.270	.314	.360	.403	.450	.493	.540	.627	.718	.900	1.08	1.26
1¼	.....	.....	.150	.174	.200	.224	.250	.274	.300	.350	.400	.450	.500	.550	.600	.700	.800	1.000	1.20	1.40
1⅜	.....	.....	.165	.192	.220	.247	.274	.302	.330	.383	.440	.493	.550	.603	.657	.767	.877	1.10	1.31	1.54
1½	.....	.....	.....	.218	.240	.270	.300	.330	.360	.418	.480	.540	.600	.660	.718	.836	.957	1.20	1.43	1.68
1⅝	.....	.....	.....	.226	.260	.296	.323	.357	.390	.453	.520	.583	.650	.713	.778	.907	1.04	1.30	1.56	1.81
1¾	.....	.....	.....	.....	.280	.313	.350	.383	.418	.490	.560	.630	.700	.770	.840	.977	1.12	1.40	1.67	1.95
1⅞	.....	.....	.....	.....	.300	.337	.373	.411	.448	.523	.598	.673	.750	.823	.897	1.05	1.20	1.50	1.80	2.10
2	.....	.....	.....	.....	.....	.358	.398	.440	.478	.560	.638	.718	.800	.878	.957	1.12	1.28	1.60	1.91	2.23
2¼	.....	.....	.....	.....	.....	.....	.448	.494	.538	.630	.718	.808	.900	.988	1.08	1.26	1.44	1.80	2.15	2.51
2½	.....	.....	.....	.....	.....	.....	.....	.548	.598	.698	.797	.898	.998	1.10	1.20	1.40	1.60	2.00	2.40	2.80
2¾	.....	.....	.....	.....	.....	.....	.....	.660	.720	.838	.957	1.08	1.21	1.32	1.43	1.68	1.91	2.40	2.79	3.35

POUNDS PER FOOT

Size, ins.	½″	⅝″	¾″	⅞″	1″	1¼″	1½″	1⅝″	1¾″	1⅞″	2″	2¼″	2½″	2¾″	3″	3½″	4″	5″	6″	7″
¼	.240	.299	.360	.419	.479	.538	.596	.658	.720	.838	.956	1.07	1.20	1.33	1.44	1.68	1.91	2.40	2.88	3.35
⅜	.359	.448	.540	.628	.719	.808	.889	.988	1.08	1.26	1.44	1.61	1.80	1.98	2.16	2.52	2.87	3.60	4.31	5.03
½	.478	.599	.720	.836	.959	1.08	1.19	1.31	1.44	1.68	1.91	2.15	2.40	2.63	2.88	3.35	3.82	4.79	5.75	6.70
⅝	.597	.747	.900	1.04	1.19	1.35	1.48	1.64	1.80	2.09	2.40	2.69	2.99	3.28	3.59	4.18	4.78	5.98	7.18	8.37
¾	.718	.897	1.08	1.26	1.44	1.61	1.79	1.97	2.15	2.51	2.87	3.23	3.60	3.95	4.31	5.02	5.74	7.20	8.62	10.03
⅞	.837	1.05	1.26	1.46	1.68	1.88	2.09	2.31	2.48	2.92	3.35	3.77	4.19	4.60	5.02	5.86	6.69	8.37	10.03	11.70
1	.....	1.20	1.44	1.68	1.91	2.15	2.40	2.63	2.87	3.35	3.83	4.31	4.79	5.26	5.74	6.70	7.65	9.59	11.48	13.40
1⅛	.....	1.35	1.62	1.88	2.15	2.42	2.69	2.96	3.23	3.77	4.31	4.84	5.38	5.92	6.46	7.52	8.61	10.75	12.94	15.08
1¼	.....	.....	1.80	2.09	2.39	2.69	2.99	3.29	3.59	4.19	4.79	5.39	5.99	6.59	7.19	8.37	9.59	11.97	14.38	16.76
1⅜	.....	.....	1.98	2.30	2.63	2.96	3.29	3.62	3.95	4.60	5.26	5.92	6.57	7.23	7.89	9.20	10.52	13.16	15.75	18.48
1½	.....	.....	.....	2.51	2.87	3.22	3.59	3.94	4.31	5.02	5.74	6.46	7.20	7.90	8.61	10.03	11.48	14.40	17.21	20.14
1⅝	.....	.....	.....	2.71	3.11	3.50	3.88	4.28	4.66	5.43	6.22	7.00	7.77	8.55	9.33	10.88	12.50	15.53	18.68	21.71
1¾	.....	.....	.....	.....	3.35	3.76	4.19	4.60	5.02	5.86	6.71	7.54	8.39	9.21	10.06	11.72	13.41	16.79	20.12	23.40
1⅞	.....	.....	.....	.....	3.59	4.04	4.48	4.93	5.38	6.28	7.18	8.07	8.97	9.87	10.76	12.60	14.40	17.90	21.50	25.20
2	.....	.....	.....	.....	.....	4.30	4.78	5.27	5.74	6.71	7.65	8.62	9.59	10.53	11.48	13.41	15.30	19.17	22.95	26.78
2¼	.....	.....	.....	.....	.....	.....	5.38	5.93	6.46	7.55	8.61	9.69	10.79	11.86	12.92	15.09	17.21	21.57	25.82	30.15
2½	.....	.....	.....	.....	.....	.....	.....	6.58	7.18	8.38	9.56	10.77	11.98	13.17	14.36	16.76	19.13	23.96	28.81	33.48
2¾	.....	.....	.....	.....	.....	.....	.....	7.90	8.63	10.06	11.48	12.93	14.38	15.80	17.21	20.12	22.95	28.76	33.43	40.16

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HIGH SPEED STEEL

WEIGHT OF ROUNDS

Lineal Measurement		
Dia. Bar Ins.	Weight per Inch	Weight per Foot
1/16	.00098	.01176
1/8	.0039	.0468
3/16	.0088	.1056
1/4	.0156	.1872
5/16	.0244	.2928
3/8	.0352	.4224
7/16	.0478	.5736
1/2	.0625	.7500
9/16	.0791	.9492
5/8	.0976	1.1712
11/16	.118	1.416
3/4	.141	1.692
13/16	.165	1.980
7/8	.191	2.292
15/16	.219	2.628
1	.248	2.976
1 1/16	.281	3.372
1 1/8	.315	3.780
1 3/16	.349	4.188
1 1/4	.397	4.764
1 5/16	.427	5.124
1 3/8	.472	5.664
1 7/16	.517	6.204
1 1/2	.562	6.744
1 9/16	.607	7.284
1 5/8	.663	7.956
1 11/16	.709	8.508
1 3/4	.765	9.180
1 13/16	.821	9.852
1 7/8	.877	10.524
1 15/16	.933	11.196
2	1.001	12.012
2 1/16	1.057	12.684
2 1/8	1.125	13.500
2 3/16	1.192	14.304
2 1/4	1.271	15.252
2 5/16	1.338	16.056
2 3/8	1.406	16.872
2 7/16	1.496	17.942
2 1/2	1.563	18.756
2 9/16	1.642	19.704
2 5/8	1.721	20.652
2 11/16	1.811	21.732
2 3/4	1.890	22.680
2 13/16	1.980	23.760
2 7/8	2.070	24.840
2 15/16	2.160	25.920
3	2.250	27.000
3 1/16	2.340	28.080
3 1/8	2.441	29.292
3 3/16	2.542	30.504
3 1/4	2.643	31.810
3 5/16	2.745	32.940
3 3/8	2.846	34.152
3 7/16	2.958	35.496
3 1/2	3.060	36.720
3 9/16	3.172	38.064
3 5/8	3.285	39.420

Lineal Measurement		
Dia. Bar Ins.	Weight per Inch	Weight per Foot
3 11/16	3.397	40.764
3 3/4	3.521	42.252
3 13/16	3.633	43.596
3 7/8	3.757	45.084
3 15/16	3.881	46.572
4	4.005	48.060
4 1/16	4.128	49.536
4 1/8	4.252	51.024
4 3/16	4.387	52.644
4 1/4	4.511	54.132
4 5/16	4.646	55.752
4 3/8	4.781	57.372
4 7/16	4.927	59.124
4 1/2	5.062	60.744
4 9/16	5.208	62.496
4 5/8	5.343	64.116
4 11/16	5.490	65.880
4 3/4	5.636	67.632
4 13/16	5.793	69.516
4 7/8	5.940	71.280
4 15/16	6.097	73.164
5	6.255	75.060
5 1/16	6.412	76.944
5 1/8	6.570	78.840
5 3/16	6.727	80.724
5 1/4	6.896	82.752
5 5/16	7.053	84.646
5 3/8	7.222	86.664
5 7/16	7.391	88.692
5 1/2	7.560	90.720
5 9/16	7.740	92.880
5 5/8	7.908	94.896
5 11/16	8.088	97.056
5 3/4	8.268	99.216
5 13/16	8.448	101.376
5 7/8	8.628	103.536
5 15/16	8.820	105.840
6	9.000	108.000
6 1/8	9.382	112.584
6 1/4	9.765	117.180
6 3/8	10.16	121.92
6 1/2	10.56	126.72
6 5/8	10.98	131.76
6 3/4	11.36	136.32
6 7/8	11.81	141.72
7	12.26	147.12
7 1/8	12.71	152.52
7 1/4	13.16	157.92
7 3/8	13.61	163.32
7 1/2	14.06	168.72
7 5/8	14.51	174.12
7 3/4	14.96	179.52
7 7/8	15.52	186.24
8	16.08	192.96

WEIGHT OF SQUARES

Lineal Measurement		
Size in Ins.	Weight per Inch	Weight per Foot
1/16	.0013	.015
1/8	.005	.060
3/16	.0113	.135
1/4	.020	.241
5/16	.031	.376
3/8	.045	.541
7/16	.061	.737
1/2	.080	.962
9/16	.101	1.217
5/8	.125	1.503
11/16	.151	1.818
3/4	.180	2.164
13/16	.212	2.540
7/8	.245	2.945
15/16	.282	3.382
1	.321	3.848
1 1/8	.406	4.869
1 1/4	.501	6.012
1 3/8	.623	7.477
1 1/2	.721	8.657
1 5/8	.847	10.160
1 3/4	.982	11.783
1 7/8	1.127	13.526
2	1.282	15.390
2 1/8	1.448	17.373
2 1/4	1.623	19.478
2 3/8	1.819	21.702
2 1/2	2.003	24.04
2 5/8	2.210	26.50
2 3/4	2.340	29.09
2 7/8	2.650	31.80
3	2.890	34.63
3 1/8	3.132	37.58
3 1/4	3.386	40.64
3 3/8	3.65	43.82
3 1/2	3.93	47.13
3 5/8	4.21	50.56
3 3/4	4.51	54.10
3 7/8	4.82	57.77
4	5.13	61.56
4 1/4	5.79	69.49
4 1/2	6.50	77.91
4 3/4	7.23	86.81
5	8.02	96.19
5 1/4	8.84	106.04
5 1/2	9.70	116.38
5 3/4	10.60	127.20
6	11.54	138.51
7	15.71	188.53
8	20.52	246.24
9	25.97	311.65
10	32.06	384.75
11	38.80	465.55
12	46.17	554.04

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WEIGHTS OF FLAT CARBON BAR STEEL—PER FOOT

	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1⅝	1¾	2	2¼	2½	2¾	3	
1/16	.1060	.1381	.1594	.1859	.212	.2391	.2656	.292	.319	.346	.372	.425	.478	.531	.584	.638	1/16
1/8	.2125	.2656	.3188	.3720	.425	.4782	.5312	.585	.638	.692	.744	.850	.96	1.06	1.17	1.28	1/8
3/16	.319	.399	.478	.558	.638	.717	.797	.875	.957	1.04	1.15	1.28	1.44	1.59	1.75	1.91	3/16
1/4	.425	.531	.636	.743	.850	.957	1.06	1.17	1.28	1.38	1.49	1.70	1.92	2.12	2.34	2.55	1/4
5/16	.531	.664	.797	.929	1.06	1.20	1.33	1.46	1.59	1.73	1.86	2.12	2.39	2.65	2.92	3.19	5/16
3/8	.638	.797	.957	1.116	1.28	1.43	1.59	1.76	1.92	2.08	2.23	2.55	2.87	3.19	3.51	3.83	3/8
7/16	.744	.929	1.116	1.302	1.49	1.68	1.86	2.05	2.23	2.42	2.60	2.98	3.35	3.72	4.09	4.46	7/16
1/2	.850	1.06	1.275	1.487	1.70	1.92	2.12	2.34	2.55	2.72	2.98	3.40	3.83	4.25	4.67	5.10	1/2
9/16	.957	1.20	1.434	1.674	1.92	2.15	2.39	2.63	2.87	3.11	3.35	3.83	4.30	4.78	5.26	5.74	9/16
5/8	1.06	1.33	1.594	1.859	2.12	2.39	2.65	2.92	3.19	3.46	3.72	4.25	4.78	5.31	5.84	6.38	5/8
11/16	1.17	1.46	1.753	2.045	2.34	2.63	2.92	3.22	3.51	3.80	4.09	4.67	5.26	5.84	6.43	7.02	11/16
3/4	1.28	1.60	1.913	2.232	2.55	2.87	3.19	3.51	3.83	4.15	4.47	5 10	5.75	6.38	7.02	7.65	3/4
13/16	1.38	1.73	2.072	2.417	2.76	3.11	3.45	3.80	4.14	4.49	4.84	5.53	6.21	6.90	7.60	8.29	13/16
7/8	1.49	1.86	2.232	2.604	2.98	3.35	3.72	4.09	4.47	4.84	5.20	5.95	6.69	7.44	8.18	8.93	7/8
15/16	1.60	1.99	2.391	2.789	3.19	3.59	3.99	4.39	4.78	5.18	5.58	6 38	7.18	7.97	8.77	9.57	15/16
1	1.70	2.13	2.55	2.98	3.40	3.83	4.25	4.68	5.10	5.53	5.95	6.80	7.65	8.50	9.35	10.20	1
1 1/16	1.91	2.39	2.87	3.35	3.83	4.30	4.78	5.26	5.74	6.22	6.70	7.65	8.61	9.57	10.52	11.48	1 1/16
1 1/4	2.12	2.66	3.19	3.72	4.25	4.79	5.31	5.85	6.38	6.91	7.44	8.50	9.57	10.63	11.69	12.75	1 1/4
1 3/16	2.34	2.92	3.51	4.09	4.67	5.26	5.84	6.43	7.02	7.60	8.18	9.35	10.52	11.69	12.85	14.03	1 3/16
1 1/2	2.55	3.19	3.83	4.47	5.10	5.74	6.38	7.02	7.65	8.29	8.93	10.20	11.48	12.75	14.03	15.30	1 1/2
1 5/8	2.76	3.45	4.15	4.84	5.52	6.22	6.90	7.60	8.29	8.98	9.67	11.05	12.43	13.81	15.19	16.58	1 5/8
1 3/4	2.98	3.72	4.47	5.21	5.95	6.70	7.44	8.19	8.93	9.67	10.42	11.90	13.40	14.88	16.37	17.85	1 3/4
1 7/8	3.19	3.99	4.79	5.58	6.38	7.17	7.97	8.77	9.57	10.36	11.15	12.75	14.34	15.94	17.53	19.13	1 7/8
2	3.40	4.25	5.10	5.95	6.80	7.65	8.50	9.35	10.20	11.05	11.90	13.60	15.30	17.00	18.70	20.40	2

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WEIGHTS OF FLAT CARBON BAR STEEL—PER FOOT

	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7	
1/16	.691	.741	.80	.85	.90	.96	1.01	1.06	1.12	1.17	1.22	1.27	1.33	1.38	1.43	1.49	1/16
1/8	1.38	1.49	1.59	1.70	1.81	1.91	2.02	2.13	2.23	2.34	2.44	2.55	2.66	2.76	2.87	2.97	1/8
3/16	2.07	2.23	2.39	2.55	2.71	2.87	3.03	3.19	3.35	3.51	3.67	3.83	3.99	4.14	4.30	4.46	3/16
1/4	2.76	2.98	3.19	3.40	3.61	3.83	4.04	4.25	4.46	4.67	4.89	5.10	5.31	5.53	5.74	5.95	1/4
5/16	3.45	3.72	3.99	4.25	4.52	4.78	5.05	5.31	5.58	5.84	6.11	6.38	6.64	6.90	7.17	7.44	5/16
3/8	4.15	4.47	4.78	5.10	5.42	5.74	6.06	6.38	6.69	7.02	7.34	7.65	7.97	8.29	8.61	8.93	3/8
7/16	4.83	5.20	5.58	5.95	6.32	6.70	7.07	7.44	7.81	8.18	8.56	8.93	9.29	9.67	10.04	10.41	7/16
1/2	5.53	5.95	6.38	6.80	7.22	7.65	8.08	8.50	8.93	9.35	9.77	10.20	10.63	11.05	11.48	11.90	1/2
9/16	6.22	6.70	7.17	7.65	8.13	8.61	9.09	9.57	10.04	10.52	11.00	11.48	11.95	12.43	12.91	13.39	9/16
5/8	6.91	7.44	7.97	8.50	9.03	9.57	10.10	10.63	11.16	11.69	12.22	12.75	13.28	13.81	14.34	14.87	5/8
11/16	7.60	8.18	8.76	9.35	9.93	10.52	11.11	11.69	12.27	12.85	13.44	14.03	14.61	15.20	15.78	16.36	11/16
3/4	8.29	8.93	9.57	10.20	10.84	11.48	12.12	12.75	13.39	14.03	14.67	15.30	15.94	16.58	17.22	17.85	3/4
13/16	8.98	9.67	10.36	11.05	11.74	12.43	13.12	13.81	14.50	15.19	15.88	16.58	17.27	17.95	18.65	19.34	13/16
7/8	9.67	10.41	11.16	11.90	12.65	13.39	14.13	14.87	15.62	16.36	17.10	17.85	18.60	19.34	20.08	20.83	7/8
15/16	10 36	11.16	11.95	12.75	13.55	14.34	15.14	15.94	16.74	17.53	18.33	19.13	19.92	20.72	21.51	22.32	15/16
1	11.05	11.90	12.75	13.60	14.45	15.30	16.15	17.00	17.85	18.70	19.55	20.40	21.25	22.10	22.95	23.80	1
1 1/16	12.43	13.39	14.34	15.30	16.26	17.22	18.17	19.13	20.08	21.04	21.99	22.95	23.91	24.87	25.82	26.78	1 1/16
1 1/8	13.81	14.87	15.94	17.00	18.06	19.13	20.19	21.25	22.32	23.38	24.44	25.50	26.56	27.62	28.69	29.75	1 1/8
1 3/16	15.20	16.36	17.53	18.70	19.87	21.04	22.21	23.38	24.54	25.71	26.88	28.05	29.22	30.39	31.56	32.72	1 3/16
1 1/4	16.58	17.85	19.13	20.40	21.68	22.95	24.23	25.50	26.78	28.05	29.33	30.60	31.88	33.15	34.43	35.70	1 1/4
1 5/16	17.96	19.34	20.72	22.10	23.48	24.87	26.25	27.63	29.01	30.39	31.77	33.15	34.53	35.91	37.99	38.67	1 5/16
1 3/8	19.34	20.83	22.32	23.80	25.29	26.78	28.27	29.75	31.24	32.73	34.22	35.70	37.19	38.68	40.17	41.65	1 3/8
1 7/16	20.72	22.31	23.91	25.50	27.10	28.69	30.28	31.87	33.47	35.06	36.65	38.25	38.85	41.44	43.03	44.63	1 7/16
2	22.10	23.80	25.50	27.20	28.90	30.60	32.30	34.00	35.70	37.40	39.10	40.80	42.50	44.20	45.90	47.60	2

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WEIGHTS OF

ROUND OCTAGON SQUARE HEXAGON

CARBON BAR STEEL PER FOOT

Size	Round	Square	Octagon	Hexagon
1/8	.042	.053	.04	.05
3/16	.094	.120	.10	.10
1/4	.167	.213	.18	.18
5/16	.261	.332	.28	.29
3/8	.376	.478	.40	.41
7/16	.511	.651	.54	.56
1/2	.668	.850	.70	.74
9/16	.845	1.076	.89	.93
5/8	1.043	1.328	1.10	1.15
11/16	1.262	1.607	1.33	1.40
3/4	1.502	1.913	1.58	1.66
13/16	1.763	2.245	1.86	1.94
7/8	2.044	2.603	2.16	2.25
15/16	2.347	2.989	2.48	2.59
1	2.670	3.400	2.82	2.94
1 1/8	3.379	4.303	3.56	3.73
1 1/4	4.173	5.312	4.40	4.60
1 3/8	5.049	6.428	5.29	5.54
1 1/2	6.008	7.650	6.34	6.63
1 5/8	7.051	8.978	7.44	7.78
1 3/4	8.178	10.41	8.64	9.02
1 7/8	9.388	11.95	9.90	10.36
2	10.68	13.60	11.26	11.78
2 1/8	12.06	15.35	12.71	13.30
2 1/4	13.52	17.22	14.26	14.91
2 3/8	15.07	19.18	15.88	16.62
2 1/2	16.69	21.25	17.60	18.41

Note: For weight of high speed steel add 13%.

Note: See page 139.

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WEIGHT OF CARBON BAR STEEL PER FOOT—Continued

Size	Round	Square	Octagon	Hexagon
2⅝	18.40	23.43	19.41	20 30
2¾	20.20	25.71	21.28	22.28
2⅞	22.07	28.10	23.28	24.34
3	24.03	30.60	25.36	26 51
3⅛	26.08	33.20	27.50	28.77
3¼	28.20	35.92	29.74	31.10
3⅜	30.42	38.73	32.10	33.55
3½	32.71	41.65	34.50	36.08
3⅝	35.09	44 68	37.01	38.70
3¾	37.56	47.82	39.61	41.43
4	42.73	54.40	45.07	47.13
4¼	48.24	61.41	50.88	53.21
4½	54.07	68.85	57.03	59.64
4¾	60.25	76.71	63.55	66.46
5	66.76	85.00	70.41	73.64
5¼	73.60	93.72	77.63	81.18
5½	80.77	102.80	85.19	89.09
5¾	88.29	112.40	93.12	97.38
6	96.14	122 40	101.45	106.04
6½	112.8	143.6	119.	124.42
7	130.9	166.6	138.1	144.38
8	171.0	217.6	180.48	188.61
9	216.3	275.4	228.1	238.58
10	267.0	340.0	281.6	294.50
11	323.1	411.4	340.6	356.38
12	384.5	489.6	405.8	428.64

Note: For weight of high speed steel add 13%.
Note: See page 139.

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WEIGHT OF STEEL

BARS

For hot-worked steel of .50 per cent carbon:

One cubic inch weighs 0.2833 pounds.

One cubic foot weighs 489.54 pounds.

Specific gravity 7.854.

For Mohawk high speed steel, add 13 per cent.

The table of weights for hot-worked straight carbon bar steel on pages 134-135 are calculated from the unit, 1 cubic inch=0.2833 pound or its equivalent 1 cubic foot=489.54 pounds. A convenient unit much used in practise is 1 cubic inch = 0.3 pound, which gives weights about 6 per cent heavier than those in the tables. Since bar-steel is usually furnished slightly full to size, weights calculated on this approximate basis yield fairly close working results for all except very large sizes.

STRIPS AND WIRE

Cold-rolled and drawn steel weighs slightly less than hot-rolled or hammered steel: 1 cubic inch weighs 0.28313 pound. Specific gravity 7.848.

To figure approximately the weight of Cold-Rolled Steel or Flat Wires:

Divide the thickness, in thousandths of an inch, by 300; the quotient will be the weight per foot of a strip 1 inch wide. Or divide by 25; the quotient will be the weight of one square foot.

EXAMPLES

Thickness of strip in thousandths, 120
divided by 300=0.4 pound per foot for a 1-inch strip;
divided by 25=4.8 pounds for 1 square foot.

Thickness of strip in thousandths, 18
divided by 300=.06 pound per foot for a one inch strip;
divided by 25=.72 pound for 1 square foot.

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OCTAGON AND HEXAGON CARBON BARS

The weight per foot of Octagon Steel is found by multiplying the weight per foot of a Round Bar of the same size by 1.0547. (See pages 136-137.)

The weight per foot of Hexagon Steel is found by multiplying the weight per foot of a Round Bar of the same size by 1.1026. (See pages 136-137.)

HALF-ROUND, OVAL AND HALF-OVAL BAR STEEL

One cubic foot weighing 48954 pounds

Half Round, Inch	Oval Inch	Pounds per Foot	Half-Oval Inch	Pounds per Foot
3/8	3/8 x 3/16	186	3/8 x 3/32	093
7/16	7/16 x 7/32	253	7/16 x 7/64	127
1/2	1/2 x 1/4	331	1/2 x 1/8	165
5/8	5/8 x 5/16	517	5/8 x 5/32	259
3/4	3/4 x 3/8	744	3/4 x 3/16	372
7/8	7/8 x 7/16	1.013	7/8 x 7/32	507
1	1 x 1/2	1.323	1 1/2 x 1/4	662
1 1/8	1 1/8 x 9/16	1.624	1 1/8 x 9/32	812
1 1/4	1 1/4 x 5/8	2.067	1 1/4 x 5/16	1.034
1 1/2	1 1/2 x 3/4	2.976	1 1/2 x 3/8	1.488
1 3/4	1 3/4 x 7/8	4.059	1 3/4 x 7/16	2.026
2	2 x 1	5.299	2 x 1/2	2.645

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WIRE GAUGES

Sizes in Decimal Parts of an Inch

Number of Wire Gauge	American or Brown and Sharpe Gauge	Birmingham or Stub's Iron Wire	Pounds per foot 1 inch wide B. W. G.	Washburn and Moen, Roebling or Steel Wire Gauge	British Imperial or Standard Gauge S. W. G.	Polished Drill-Rod or Stub's Steel Wire	Morse Twist Drill Gauge
0000000	.....	.....	.....	.49	.500	.....	.....
000000	.....	.....	.....	.46	.464	.....	.....
00000	.....	.....	.....	.43	.432	.....	.....
0000	.460	.454	1.512	.3938	.400	.....	.....
000	.40964	.425	1.415	.3625	.372	.....	.....
00	.3648	.380	1.265	.3310	.348	.....	.....
0	.32486	.340	1.132	.3065	.324	.....	.....
1	.2893	.300	1.000	.2830	.300	.227	.2280
2	.25763	.284	.946	.2625	.276	.219	.2210
3	.22942	.259	.863	.2437	.252	.212	.2130
4	.20431	.238	.793	.2253	.232	.207	.2090
5	.18194	.220	.733	.2070	.212	.204	.2055
6	.16202	.203	.676	.1920	.192	.201	.2040
7	.14428	.180	.600	.1770	.176	.199	.2010
8	.12849	.165	.550	.1620	.160	.197	.1990
9	.11443	.148	.493	.1483	.144	.194	.1960
10	.10189	.134	.446	.1350	.128	.191	.1935
11	.090742	.120	.400	.1205	.116	.188	.1910
12	.080808	.109	.363	.1055	.104	.185	.1890
13	.071961	.095	.316	.0915	.092	.182	.1850

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WIRE GAUGES—*Continued*

Sizes in Decimal Parts of an Inch

Number of Wire Gauge	American or Brown and Sharpe Gauge	Birmingham or Stub's Iron Wire	Pounds per foot 1 inch wide B. W. G.	Washburn and Moen, Roebling or Steel Wire Gauge	British Imperial or Standard Gauge S. W. G.	Polished Drill-Rod or Stub's Steel Wire	Morse Twist Drill Gauge
14	.064084	.083	.276	.0800	.080	.180	.1820
15	.057068	.072	.240	.0720	.072	.178	.1800
16	.05082	.065	.217	.0625	.064	.175	.1770
17	.045257	.058	.193	.0540	.056	.172	.1730
18	.040303	.049	.165	.0475	.048	.168	.1695
19	.03589	.042	.140	.0410	.040	.164	.1660
20	.031961	.035	.117	.0348	.036	.161	.1610
21	.028462	.032	.107	.03175	.032	.157	.1590
22	.025347	.028	.093	.0286	.028	.155	.1570
23	.022571	.025	.083	.0258	.024	.153	.1540
24	.0201	.022	.073	.0230	.022	.151	.1520
25	.0179	.02	.067	.0204	.020	.148	.1495
26	.01594	.018	.060	.0181	.018	.146	.1470
27	.014195	.016	.053	.0173	.0164	.143	.1440
28	.012641	.014	.047	.0162	.0149	.139	.1405
29	.011257	.013	.044	.0150	.0136	.134	.1360
30	.010025	.012	.040	.0140	.0124	.127	.1285
31	.008928	.01	.0333	.0132	.0116	.120	.1200
32	.00795	.009	.0300	.0128	.0108	.115	.1160
33	.00708	.008	.0266	.0118	.0110	.112	.1130

For fractions of one inch in decimal equivalents, see page 145.

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UNITED STATES OFFICIAL MILLIMETERS CONVERSION TABLE

Millimeters	Equivalent in Inches	Millimeters	Equivalent in Inches	Millimeters	Equivalent in Inches	Millimeters	Equivalent in Inches
1	0.03,937	26	1.02,362	51	2.00.787	76	2.99,212
2	0.07,874	27	1.06,299	52	2.04,724	77	3.03,149
3	0.11.811	28	1.10,236	53	2.08,661	78	3.07,086
4	0.15,748	29	1.14,173	54	2.12,598	79	3.11,023
5	0.19,685	30	1.18,110	55	2.16 535	80	3.14,960
6	0.23,622	31	1.22,047	56	2.20,472	81	3.18,897
7	0.27,559	32	1.25,984	57	2.24,409	82	3.22,834
8	0.31,496	33	1.29,921	58	2.28,346	83	3.26,771
9	0.35,433	34	1.33,858	59	2.32,283	84	3.30.708
10	0.39,370	35	1.37,795	60	2.36,220	85	3.34,645
11	0.43,307	36	1.41,732	61	2.40,157	86	3.38,582
12	0.47,244	37	1.45,669	62	2.44.094	87	3.42,519
13	0.51,181	38	1.49,606	63	2.48,031	88	3.46,456
14	0.55,118	39	1 53,543	64	2.51,968	89	3.50,393
15	0.59,055	40	1.57,480	65	2.55,905	90	3.54,330
16	0.62,992	41	1.61,417	66	2.59,842	91	3.58,267
17	0.66,929	42	1.65.354	67	2.63,779	92	3.62,204
18	0.70,866	43	1.69,291	68	2.67,716	93	3.66,141
19	0.74,803	44	1.73,228	69	2.71,653	94	3.70,078
20	0.78,740	45	1.77,165	70	2.75,590	95	3.74,015
21	0.82,677	46	1.81,102	71	2.79,527	96	3.77,952
22	0.86,614	47	1.85.039	72	2.83,464	97	3.81,889
23	0.90,551	48	1.88,976	73	2.87,401	98	3.85,826
24	0.94,488	49	1.92,913	74	2.91,338	99	3.89,763
25	0.98.425	50	1.96,850	75	2.95.275	100	3.93,700

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METRIC CONVERSION FACTORS

1 gram = 15.432 grains
1 meter = 39.371 inches or 3.28083 feet
1 millimeter = 0.03937 inch, or $\frac{1}{25}$ in. approx.
1 metric ton = 2204.6 pounds or
1000 kilograms = .9842 ton of 2240 pounds
1.016 metric ton = 1 ton of 2240 pounds.
1016 kilograms

Unit	Inches to Millimeters	Millimeters to inches	Pounds to Kilograms	Kilograms to Pounds
1	25.4001	.039371	0.45359	2.20462
2	50.8001	.078742	0.90719	4.40924
3	76.2002	.118112	1.36078	6.61386
4	101.6002	.157483	1.81437	8.81849
5	127.0003	.196854	2.26796	11.02311
6	152.4003	.236225	2.72156	13.22773
7	177.8004	.275596	3.17515	15.43235
8	203.2004	.314966	3.62874	17.63697
9	228.6005	.354337	4.08233	19.84159
10	254.0006	.393708	4.35592	22.04622
11	279.4007	.433079	4.98951	24.25084
12	304.8006	.472450	5.44312	26.45546
13	330.2007	.511821	5.89671	28.66008
14	355.6008	.551192	6.35030	30.86470
15	381.0002	.590563	6.80389	33.06932
16	406.4008	.629932	7.25748	35.27394
17	431.8009	.669303	7.71107	36.47856
18	457.2010	.708674	8.16566	39.68318
19	482.6011	.748045	8.61925	41.88780

1 kilogram per sq. centimeter = 14.2234 lbs. per sq. in.
1 kilogram per sq. millimeter = 1422.32 lbs. per sq. in.
1000 lbs. per sq. in. = 0.70308 kilograms per sq. mi.
70.308 kilograms per sq. cm.

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FRACTIONS OF ONE MILLIMETER IN EQUIVALENT DECIMALS OF AN INCH

.01 MM. = .0003937 inch

MM. Inches	MM. Inches
.02=.00079	.52=.02047
.04=.00157	.54=.02126
.06=.00236	.56=.02205
.08=.00315	.58=.02283
.10=.00394	.60=.02362
.12=.00472	.62=.02441
.14=.00551	.64=.02520
.16=.00630	.66=.02598
.18=.00709	.68=.02677
.20=.00787	.70=.02756
.22=.00866	.72=.02835
.24=.00945	.74=.02913
.26=.01024	.76=.02992
.28=.01102	.78=.03071
.30=.01181	.80=.03150
.32=.01260	.82=.03228
.34=.01339	.84=.03307
.36=.01417	.86=.03386
.38=.01496	.88=.03465
.40=.01575	.90=.03543
.42=.01654	.92=.03622
.44=.01732	.94=.03701
.46=.01811	.96=.03780
.48=.01890	.98=.03858
.50=.01969	1=.03937

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FRACTIONS OF ONE INCH IN DECIMAL EQUIVALENTS

8ths	32nds cont'd	64ths cont'd
$\frac{1}{8}$ = .125	$\frac{9}{32}$ = .28125	$\frac{19}{64}$ = .296875
$\frac{1}{4}$ = .25	$\frac{11}{32}$ = .34375	$\frac{21}{64}$ = .328125
$\frac{3}{8}$ = .375	$\frac{13}{32}$ = .40625	$\frac{23}{64}$ = .359375
$\frac{1}{2}$ = .50	$\frac{15}{32}$ = .46875	$\frac{25}{64}$ = .390625
$\frac{5}{8}$ = .625	$\frac{17}{32}$ = .53125	$\frac{27}{64}$ = .421875
$\frac{3}{4}$ = .75	$\frac{19}{32}$ = .59375	$\frac{29}{64}$ = .453125
$\frac{7}{8}$ = .875	$\frac{21}{32}$ = .65625	$\frac{31}{64}$ = .484375
	$\frac{23}{32}$ = .71875	$\frac{33}{64}$ = .515625
16ths	$\frac{25}{32}$ = .78125	$\frac{35}{64}$ = .546875
$\frac{1}{16}$ = .0625	$\frac{27}{32}$ = .84375	$\frac{37}{64}$ = .578125
$\frac{3}{16}$ = .1875	$\frac{29}{32}$ = .90625	$\frac{39}{64}$ = .609375
$\frac{5}{16}$ = .3125	$\frac{31}{32}$ = .96875	$\frac{41}{64}$ = .640625
$\frac{7}{16}$ = .4375		$\frac{43}{64}$ = .671875
$\frac{9}{16}$ = .5625	64ths	$\frac{45}{64}$ = .703125
$\frac{11}{16}$ = .6875	$\frac{1}{64}$ = .015625	$\frac{47}{64}$ = .734375
$\frac{13}{16}$ = .8125	$\frac{3}{64}$ = .046875	$\frac{49}{64}$ = .765625
$\frac{15}{16}$ = .9375	$\frac{5}{64}$ = .078125	$\frac{51}{64}$ = .796875
	$\frac{7}{64}$ = .109375	$\frac{53}{64}$ = .828125
32nds	$\frac{9}{64}$ = .140625	$\frac{55}{64}$ = .859375
$\frac{1}{32}$ = .03125	$\frac{11}{64}$ = .171875	$\frac{57}{64}$ = .890625
$\frac{3}{32}$ = .09375	$\frac{13}{64}$ = .203125	$\frac{59}{64}$ = .921875
$\frac{5}{32}$ = .15625	$\frac{15}{64}$ = .234275	$\frac{61}{64}$ = .953125
$\frac{7}{32}$ = .21875	$\frac{17}{64}$ = .265625	$\frac{63}{64}$ = .984375

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TO CONVERT A DECIMAL INTO A COMMON FRACTION

Set down the decimal as a numerator, and place as the denominator 1 with as many ciphers annexed as there are decimal places in the numerator; erase the decimal point in the numerator and reduce the fraction thus formed to its lowest terms:

$$0.125 = \frac{125}{1000} = \frac{1}{8}$$

$$0.3333 = \frac{3333}{10000} = \frac{1}{3} \text{ approx.}$$

TO CONVERT A COMMON FRACTION INTO A DECIMAL

Divide the numerator by the denominator, adding to the numerator as many ciphers prefixed by a decimal point as are necessary to give the number of decimal places desired in the result:

$\frac{1}{3} = 1.0000 \div 3 = 0.333$ plus

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TABLE OF HARDNESS NUMERALS FOR USE IN THE BRINELL TEST

Steel Ball of 10 MM. Diameter

Diameter of Impression in MM.	Hardness Numeral Pressure in k'gs. 3000	500	Diameter of Impression in MM.	Hardness Numeral Pressure in k'gs. 3000	500	Diameter of Impression in MM.	Hardness Numeral Pressure in kg's, 3000	500	Diameter of Impression in MM.	Hardness Numeral Pressure in k'gs. 3000	500	Diameter of Impression in MM.	Hardness Numeral Pressure in k'gs. 3000	500
2.00	946	158	3.00	418	69.7	4.00	228	38.	5.00	143	23.8	6.00	95	15.8
2.05	898	150	3.05	402	67.0	4.05	223	37.2	5.05	140	23.3	6.05	94	15.7
2.10	857	143	3.10	387	64.5	4.10	217	36.2	5.10	137	22.8	6.10	92	15.3
2.15	817	136	3.15	375	62.5	4.15	212	35.3	5.15	134	22.3	6.15	90	15.
2.20	782	130	3.20	364	60.7	4.20	207	34.5	5.20	131	21.8	6.20	89	14.8
2.25	744	124	3.25	351	58.5	4.25	202	33.7	5.25	128	21.3	6.25	87	14.5
2.30	713	119	3.30	340	56.7	4.30	196	32.7	5.30	126	21.	6.30	86	14.3
2.35	683	114	3.35	332	55.3	4.35	192	32.	5.35	124	20.7	6.35	84	14.
2.40	652	109	3.40	321	53.5	4.40	187	31.2	5.40	121	20.2	6.40	82	13.7
2.45	627	105	3.45	311	51.8	4.45	183	30.5	5.45	118	19.7	6.45	81	13.5
2.50	600	100	3.50	302	50.3	4.50	179	29.8	5.50	116	19.3	6.50	80	13.3
2.55	578	96.3	3.55	293	48.8	4.55	174	29.	5.55	114	19.	6.55	79	13.2
2.60	555	92.5	3.60	286	47.7	4.60	170	28.3	5.60	112	18.7	6.60	77	12.8
2.65	532	88.7	3.65	277	46.2	4.65	166	27.7	5.65	109	18.2	6.65	76	12.7
2.70	512	85.3	3.70	269	44.8	4.70	163	27.2	5.70	107	17.8	6.70	74	12.3
2.75	495	82.5	3.75	262	43.7	4.75	159	26.5	5.75	105	17.5	6.75	73	12.2
2.80	477	79.5	3.80	255	42.5	4.80	156	26.	5.80	103	17.2	6.80	71	11.8
2.85	460	76.7	3.85	248	41.3	4.85	153	25.5	5.85	101	16.8	6.85	70	11.7
2.90	444	74.0	3.90	241	40.2	4.90	149	24.8	5.90	99	16.5	6.90	69	11.5
2.95	430	71.7	3.95	235	39.2	4.95	146	24.3	5.95	97	16.2	6.95	68	11.3

NOTES

All very hard materials such as iron, steel etc. to be tested at a load of 3000 k'g. Softer materials to be tested at a load of 500 k'g. Numerals given $= \frac{P}{A}$ where P is the pressure in k'gs and A is the area of the impression in square millimeters.

In order to determine the ultimate strength of the specimen by this test it will be necessary to establish, by experiment, a coefficient by which to multiply the hardness numerals.

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USEFUL INFORMATION

To find the area of a circle, multiply the square of the diameter by .7854.

To find the area of an octagon, multiply the square of the diameter of the inscribed circle by .828

To find the area of a hexagon, multiply the square of the diameter of the inscribed circle by .866.

To find the area of a triangle, multiply the base by one-half the perpendicular height.

To find the area of a trapezoid, add the two parallel sides together and multiply the sum by half the perpendicular distance between them.

To find the area of the section of a flat bar, or the area of a rectangle, multiply the width by the thickness.

To find the number of cubic inches in any bar, multiply the area of its section in inches by its length in inches.

The weight of one cubic foot of steel is approximately 490 pounds.

The weight of one cubic inch of steel is approximately .285 pound.

The specific gravity of steel is approximately 7.85, while that of grey cast-iron averages 7.22, and white iron 7.65.

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Having the number of cubic inches in any bar, to find its weight in carbon steel, multiply by .2833 if exact weight is desired; or multiply by .3 if a practical weight is wanted. For the weight of wrought iron, multiply the cubic inches by .28. For the weight of cast iron, multiply the cubic inches by .26.

Steels of the high speed types are much heavier than ordinary tool steel. Thus while the specific gravity of ordinary tool steel is 7.85, that of high speed steels varies from 8.45 to 8.75, depending upon the percentage of chromium and tungsten present. In estimating weights of high speed bars, therefore, one must increase the weights as given in this book by from 12 to 14 per cent. In general, one may consider high speed steel as 13 per cent heavier than tool steel.

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